Ocular exposure to occupational non-ionising radiation in professional pilots

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Abstract

Research evidence supports the link between long term exposure to ultraviolet (UV) and the blue light hazard with ocular damage including cataract and macular degeneration. Population studies to determine the prevalence of these conditions in pilots are inconclusive. It is known that UV and blue light intensities increase with altitude. The aim of this research was to investigate whether professional pilots are adequately protected from UV and short wavelength light during flight.
Informed by the results of 22 semi-structured interviews, a questionnaire exploring the eye protection habits of professional pilots was developed and completed by 2,967 participants. The results showed a wide variation in pilot use of sunglasses, uncovered barriers preventing sunglass use and showed a high level of dissatisfaction regarding standard aircraft sun protection systems.

In flight irradiance measurements were captured during 6 airline and 4 helicopter flights. No measurable UVB was found. UVA exposure was highly reliant on the transmission properties of the aircraft windshield. Further ground measurements on 15 aircraft showed the majority had windshields which transmit significant levels of UVA into the cockpit. This can cause the ocular dose for the unprotected eye to exceed international recommended exposure limits within ½ hour of flight. Older aircraft generally had superior UVA blocking windshields. Although calculated retinal exposure to blue light hazard during flight fell well within international recommended limits, the mean radiance was 4.1 times higher at altitude. The effect of this over a flying career remains uncertain.

Filter transmittance measurements were taken from 34 pilot sunglasses and 20 new sunglasses typically used by pilots. All sunglasses filters measured offered sufficient protection from UVA in flight and ensured an attenuation of the blue light hazard to levels equivalent to those at ground level without protection.

A series of practical recommendations are made to pilots, eye care health professionals, industry and the aviation regulators.

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List of abbreviations

AMD – Age-related macular degeneration

CAA – Civil Aviation Authority

CCD – Charge-Coupled Device

CRM – Crew Resource Management

EFIS – Electronic Flight Information System

FL – Flight Level

FOI – Flight Operations Inspector

GMT – Greenwich Mean Time

HOS – Helicopter off-shore operation

IR – infrared

LH – Long haul airline operation

MED – minimal erythemal dose

nm - nanometers

SED – standard erythemal dose

SH – Short haul airline operation

UTC – Coordinated Universal Time

UV – ultraviolet

UVA – ultraviolet radiation within the waveband 200-280nm

UVB - ultraviolet radiation within the waveband 280-315nm

UVC - ultraviolet radiation within the waveband 315-400nm

VDL – pilot spectacle limitation: *'Shall wear corrective lenses and carry a spare set of spectacles'*

VNL – pilot spectacle limitation: *'Shall have available corrective lenses'*

Glossary of terms

Accommodation – adjustment of the dioptric power of the eye to clearly see objects at any distance.

Ametrope – person who has ametropia.

Ametropia – anomaly of the refractive state of the eye in which, with relaxed accommodation, the image of objects at infinity is not focused on the retina. Ametropias are astigmatism, hypermetropia and myopia.

Aphakia / Aphakic – ocular condition in which the crystalline lens is absent.

Asthenopia – subjective symptoms of ocular fatigue associated with use of the eyes.

Aviator sunglasses - denoting a style of sunglasses having a thin wire frame and oval large lenses that narrow toward the bridge of the nose.

Disability glare - a bright light source which increases scattered light within the eye and casts a veiling luminance on the retina, reducing contrast and affecting vision.

Discomfort glare - resulting from of an overly bright environment and causing symptoms of discomfort.

Emmetrope – person who has emmetropia.

Emmetropia – the refractive state of the eye in which, with relaxed accommodation, the image of objects at infinity is focused on the retina.

Illuminance – a photometric measure of total luminous flux per unit area.

Irradiance – the incident power per unit surface area.

Peripheral Light Focusing (PLF) effect – the focusing of solar ultraviolet (UV) radiation from the temporal edge of the cornea to the nasal edge of the cornea.

Photoconjunctivitis – painful injury to the conjunctiva caused by overexposure to ultraviolet (UV) radiation.

Photokeratitis - painful injury to the cornea caused by overexposure to ultraviolet (UV) radiation.

Presbyope – person who has presbyopia.

Presbyopia – refractive condition in which the accommodative ability of the eye becomes insufficient for near focus without the use of corrective plus lenses.

Pterygium – degenerative condition which causes an extension of the conjunctiva progressively across the cornea, usually from the nasal side.

Radiance - the power or radiant flux per unit solid angle and per unit projected area.

Radiant exposure – the incident energy (radiant flux per unit time) divided by surface area of the receptor.

Retinal Pigment Epithelium – the pigmented cell layer just outside the neurosensory retinal later.

Spectrometer – device that measures relative intensity at different wavelengths

Spectroradiometer – device that is calibrated to measure quantitative or absolute intensity at different wavelengths.

Transmission – the process of radiation passing through a sample.

Transmittance – the fraction of incident radiation of a specified wavelength or wavelength range which passes through a sample.

Troposphere – the lowest layer of the Earth's atmosphere

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1. Chapter 1 Introduction

CHAPTER OVERVIEW

This chapter explains the background to the initiation of this research and why the research is necessary. The nature of non-ionising solar radiation and how it is affected as it passes through the Earth's atmosphere together with the factors that are likely to affect the pilot's occupational exposure will be discussed. The issues of occupational exposure will be placed within the context of both UK law and international exposure limits. International standards for the requirements of sunglass filters will also be discussed.

1.1 Background

This thesis explores and attempts to quantify the occupational exposure to professional pilots' eyes from non-ionising radiation during flight, to indentify if there are likely to be significant risks present and where those risks may be greatest. The researcher's professional background is that of an optometrist employed by the civil aviation industry regulator, the Civil Aviation Authority (CAA), within the medical department. In addition to its enforcement roles, the CAA also provides information to pilots, industry and the general public across a wide range of aviation related topics. Pilots often enquire about CAA recommendations for sunglasses. Whilst such recommendations exist, these are not evidence-based and no previous research had been undertaken to establish if these guidelines would be appropriate given the unique visual environment of the pilot.

Advances in spectrometer technology have resulted in small, portable devices able to capture spectral irradiance which have the potential to collect data during flight without any interference to aircraft systems. A combination of these broad factors led to the development of this research, which rather than solely attempt to assess the prevalence of non-ionising radiation related pathology in the professional pilot population, sets out to determine whether current pilot eye protection practices are appropriate using the new knowledge generated of the likely ocular irradiance levels expected during flight. A key aim of this research is to produce evidence-based guidance to pilots on eye protection and sunglass selection for flight.

1.2 The electromagnetic spectrum

Electromagnetic radiation consists of two sinusoidal waves (electric and magnetic) which are perpendicular to each other and to the direction of propagation. The full electromagnetic spectrum includes radio waves, microwaves, infrared, visible light, ultraviolet, x-rays and gamma rays (Figure 1-a)

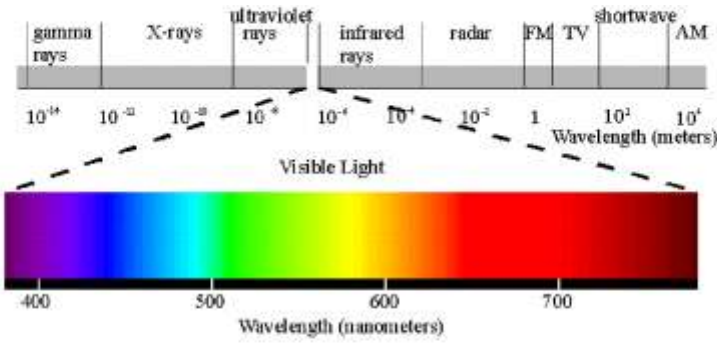

Figure 1-a Electromagnetic spectrum with expanded area showing range of visible light

Ultraviolet radiation (UV) is normally categorised into UVC (200-280nm), UVB (280-315nm) and UVA (315-400nm) (ISO 21348, 2007). Radiation between around 400nm – 780nm reaches the human retina and is termed visible light. Short wavelength visible light is perceived as blue while the longer wavelength range of the visible spectrum is perceived as red (Table 1-a).

Colour	Wavelength
violet	380-450 nm
blue	450-495 nm
green	495-570 nm
yellow	570-590 nm
orange	590-620 nm
red	620-780 nm

Table 1-a Wavelength ranges of visible light

A photon is a single unit or quantum of electromagnetic radiation. It has an energy (E), measured in Joules (J) which is related to the wavelength (λ) of radiation by the formula:

$E = h \times f$

Where *f* is the frequency of radiation, calculated by dividing speed of propagation, *c* by λ; h is Planck's constant which is 6.63×10^{-34} J. Therefore shorter wavelength radiation has higher photon energy and longer wavelength radiation has lower photon energy.

UV and visible light are part of the non-ionising portion of the electromagnetic spectrum. Wavelengths below 100nm would be considered to be ionising radiation and are not discussed as part of this research. Cosmic radiation does not form part of the electromagnetic spectrum. This is high energy radiation composed mainly of atomic nuclei and which originates from outside the solar system (Ernsting et al, 2000) and does not form part of this study.

1.3 Direct, scattered and filtered radiation

Electromagnetic radiation measured may be direct, scattered, reflected or filtered or more likely, a combination of all components. Radiation that is absorbed or reflected away from a radiation measuring device is not detected. In the case of solar radiation, scattering occurs as radiation interacts with molecules and aerosols in the air. Short wavelength radiation is more readily scattered than longer wavelengths which is known as Rayleigh scattering. Reflected radiation can contribute to a total ocular dose by being reflected back from a surface such as water, snow or, as could be the case for pilots, cloud tops. Filtered radiation is that which is found after passing through materials such as windshields or sunglasses.

The reflection of UV from a surface may be specular where the angle of incidence equals angle of reflection, or diffuse (Lambertian) where radiation is reflected equally in all directions and independent of angle of incidence. Most surfaces show a reflection of radiation between these two extreme cases (Madronich,1993). For example, grass reflects around 0.5% of incident radiation while snow reflects around 80%. Apart from the reflectivity of snow covered surfaces, the reflectivity of UV is generally lower than for visible light. For an area with different types of surface the average reflectivity is the sum of individual reflectivity weighted with the percentage of total area covered by each respective surface (Weihs et al, 2000a).

Diffuse UV radiation as a product of scattering or reflection, provides a significant proportion of UV exposure. It is incident from all directions and difficult to reduce with use of hats and shade structures (Parisi et al, 2004). There is proportionally more diffuse UV radiation in winter months due to the sun nearer the horizon (section 1.4.4). Scattered radiation has the same wavelength frequency as the incident radiation.

In the case of an overhead midday sun, the diffuse component of the total UV received is reduced due to the shorter path of radiation through the atmosphere (see section 1.4.3 – air mass). The increased UV exposures on the sun-normal plane are marginally higher in the UVA range compared to UVB due to a higher proportion of Rayleigh scattering of shorter wavelength UVB causing a higher relative proportion of diffuse UV.

1.4 Solar radiation

The Earth receives only a small proportion of the total energy radiated by the sun. The solar constant is the irradiance per unit area above the Earth's atmosphere instant on a plane normal to the sun's direction and the mean Earth-sun distance and has a value of approximately 1370W m^{-2} (Andrews, 2000). The actual solar irradiance varies by approximately 6.9% on an annual cycle as the Earth's distance to the sun varies due to its elliptical orbit by about +/-1.7% of the annual mean distance (Blumthaler, 1993). The proportion of solar radiation in the UV waveband is approximately 6% (Ambach et al, 1993). In addition to the effects of scatter, reflection and filtering, the amount of solar radiation received at any given time is also dependent on location (including latitude) and time of day.

The solar constant is affected by the solar cycle which is an approximate 11 year cyclical variation in solar output and is affected by observed activity including solar flares and sun spots. A new solar cycle began in January 2008 (NASA, 2008) with its peak reported in December 2013 although the cycle is weaker than previous cycles (Gannon, 2013). The 11 year solar activity cycle has its greatest effect on UVC levels and is minimal (less than 1%) on the Earth's surface for wavelengths greater than 300nm (Blumthaler, 1993).

The electromagnetic spectra reaching the Earth's upper atmosphere closely approximates to a black body (perfect emitter of radiation) at 5777K (Guyat, 1998). This produces a wide spectral range with a peak emission in the visible waveband and a decreasing level of UV with decreasing wavelength. The solar spectrum shows a series of distinctive Fraunhofer lines which correspond to absorption of radiation in both the sun's outer atmosphere and the Earth's atmosphere (Encyclopaedia Britannica, no date). These lines can be utilised in the calibration of spectroradiometers for solar measurements (section 5.6).

1.4.1 Structure of the atmosphere

The atmosphere is generally considered as consisting of a series of concentric shells, of varying thickness around the Earth with variations in the thickness of layers with latitude, temperature and season (Ernsting et al, 2000). The troposphere is the layer closest to the earth's surface. As warmer air rises further and warmer air is present at the equator than at the poles, the troposphere extends to a higher altitude at the equator (approximately 58,000ft) than at the poles (approximately 26,000ft). The stratosphere is the next layer which extends to an altitude of approximately 158,000ft (Ernsting et al, 2000). With increasing altitude through the troposphere, there is a temperature reduction of around 2°C per 1000ft. Additionally with increasing altitude, the Earth's gravitational effect on atmospheric gases weakens, thus both the air density and pressure decrease with altitude. This impacts upon the degree of absorption or scatter of radiation at higher altitudes.

The low atmospheric pressure found at altitude is not conducive to human survival and aircraft operating at high altitudes generally have pressurised cabins (usually to the equivalent of around 5,000 – 8,000ft) or require all crew to use breathing apparatus.

1.4.2 Atmospheric effects

Almost all solar UVC is absorbed at high altitudes and UVB is attenuated by the ozone (O_3) which is generally concentrated within 50,000 – 164,000 ft of the earth's surface (Blumthaler et al, 1997) predominantly in the stratosphere. Ozone is formed by the breakdown of O_2 into atoms of oxygen by UV radiation. The single oxygen atoms subsequently combine with other O_2 molecules to form triatomic oxygen. Fluctuations in atmospheric ozone occur on a daily and seasonal timeframe. Levels vary with latitude and time of year. Lowest levels occur within 20° of the Equator (Parisi et al, 2004).

Ozone absorption of UV peaks around 250nm with a continuum from around 200-350nm after which there is negligible absorption (Daumont et al, 1992). Ozone filters most of the UVB radiation, however UVA is far less affected by absorption due to ozone. Of the UV reaching the Earth's surface, it is estimated that 95% is UVA and 5% is UVB (Citek et al, 2011).

As discussed in section 1.3, radiation is absorbed or scattered by ozone and aerosols but also particulate matter in the atmosphere. Short wavelengths are subject to a greater degree of Rayleigh scatter due to molecular interaction. Another type of scatter, known as Mie scattering, is less wavelength dependent and caused by interaction of radiation with larger particles such as water vapour, aerosols and dust (Parisi et al, 2004). It is more likely to occur in cloud or at lower altitude and in areas of greater atmospheric pollution.

The change in UV irradiance caused by change in atmospheric ozone is not linear (Blumthaler at al, 1997). Trends in the decrease in stratospheric ozone relative to values in the 1970s are approximately 50% in the Antarctic and 15% in the Arctic. The corresponding increase in erythemal UV (section 1.4.8) is estimated as 130% in the Antarctic and 22% in the Arctic (Madronich et al, 1998). For mid-latitudes, the ozone decrease is seen in the mid 1990s is projected to return to 1980s levels before mid-century. UVB irradiances at mid latitudes is reported to be less than 5% greater than in mid 1980s (McKenzie et al, 2011). These figures take into account the 1- 2% variation in the Sun's output due to the 11 year sunspot cycle and variations due to major volcanic eruptions (Parisi et al, 2004).

Increased tropospheric pollution due to sulphur dioxide (released into the atmosphere during volcanic eruptions) and aerosols may reduce UVB reaching the ground (Tang et al, 1998). It is however likely that the effect of this additional UV filtering is reduced at airline cruising altitudes (section 1.5.2).

1.4.3 Air mass

The air mass relates to the path that direct solar radiation takes through the atmosphere to reach the observer or sensor. Where the solar position is directly overhead, radiation passes through the atmospheric layers at a normal angle and has the shortest path. When the solar position involves an increasing zenith angle (angle from the vertical overhead), a longer path is taken through the atmosphere resulting in higher absorption of UV which, in turn, results in both a lower UV irradiance and greater absorption of shorter wavelengths causing a cut-off point at a longer wavelength. Parisi et al (2001) measured UVA spectra from the same location on cloud-free days during summer and winter. The wavelength cut-off was around 290nm on a summer day and 300nm on a winter day. Conversely, reductions in ozone will lead to a shift in cut-off to shorter wavelengths resulting in more UVB irradiance.

Air Mass is calculated as 1/cos zenith angle. An Air Mass of 1 therefore relates to an overhead solar position. This formula is not valid where the sun is close to the horizon due to the earth's curvature however more complex formula can be applied in these circumstances. For a given Air Mass, the intensity of the direct component of the solar radiation can be estimated (Meinel & Meinel, 1976; Moreno et al, 2014).

1.4.4 Solar position

The relative position of the sun to an observer constantly changes with time. A number of factors affect this position including the time of year, latitudinal and longitudinal position of the observer and the time of day.

Time is generally defined relative to a standard such as Coordinated Universal Time (UTC) which starts its cycle at midnight or Greenwich Mean Time (GMT) which starts its cycle at midday. Noon in solar time is the point at which the sun is at its highest point in the sky. This measure of time varies from UTC and GMT due to eccentricity of the earth's orbit and the earth's tilt. Additionally, solar position to an observer will vary longitudinally within a time zone. In calculating a solar position, a time correction factor can be applied to correct for longitudinal variations within a time zone and eccentricity of orbit.

1.4.4.1 Latitude and declination angle

Declination angle is the angle between the equator and a line drawn from the centre of the earth to the centre of the sun. The axis of the earth's rotation is at an angle of approximately 23.45° and during its annual rotation around the sun, the declination angle varies seasonally from +23.45° at the summer solstice to -23.45° at the winter solstice. The declination angle and latitudinal position of the observer dictate the length of daylight hours of any given day.

1.4.4.2 Azimuth angle

The azimuth angle is the compass direction from which sunlight is coming and it is defined from 0° at north, 90° at east, 180° south and 270° west (Figure 1-b). It changes throughout the day and varies with latitude and time of year. The azimuth angle is either 0° or 180° at solar noon.

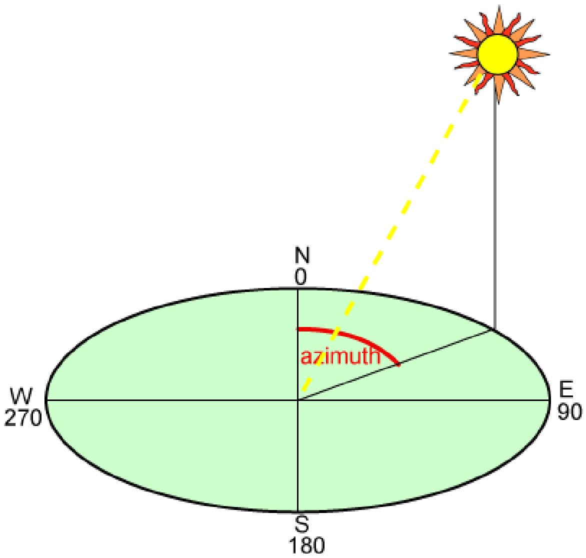

Figure 1-b Diagram showing solar azimuth angle. Green area represents the surface. Azimuth angle is the imaginary angle on the ground that the sun would subtend compared to compass points. Figure taken from pveducation.org (Honsberg and Bowden, no date a).

1.4.4.3 Elevation angle

The elevation angle is the solar positional angle from the horizon and is 90° minus the zenith angle. It varies throughout the day and is 0° at sunrise and sunset. The elevation angle also varies seasonally as the maximum angle changes. The maximum elevation angle in turn depends on latitude and declination angle. For instance between the equator and Tropic of Cancer (most northerly point where sun appears at 90° at summer solstice) in summer, the elevation angle at solar noon is greater than 90° and appears from the north rather than from the south as is the case for majority of time in Northern hemisphere. The converse is true for latitudes between Tropic of Capricorn and equator in southern hemisphere.

Due to the large distance (1.5×10^8 km) between the sun and the observer on earth, the effect on elevation angle from sea level compared to airline cruising altitude is minimal even at low elevation angles. For example, where the sun is near the horizon, the difference in elevation angle between ground and 11,000 m (approximately 36,000ft) is 4.2 x 10^{-6} degrees of arc.

1.4.4.4 Azimuth plots

The solar position throughout a defined time period can be plotted as an azimuth plot. These show both azimuth and elevation angles and can be shown graphically. The outermost ring represents a 0° elevation angle and each ring represents a 10° increase in elevation angle. The middle point represents a 90° overhead solar position (Figure 1-c).

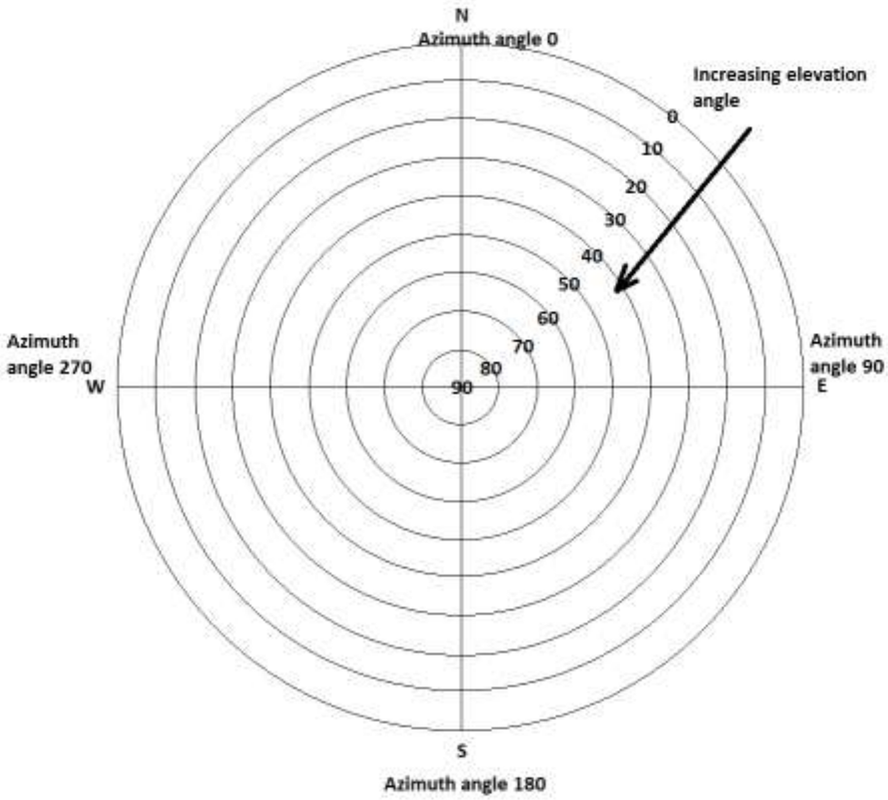

Figure 1-c Azimuth plot. Relative solar position to an observer at a particular point can be defined using azimuth angle and elevation angle.

Typically, the solar position throughout daylight at a given point is plotted with the solar position starting and finishing at the 0° elevation marker. Figure 1-d shows the approximate solar path for both summer and winter solstice for an observer in London, UK (latitude 51.5°, longitude 0.0°).

This seasonal variation causes a change in radiation received (Kimlin et al 2002). Variation in UV exposure to a horizontal plane during the day show a bell shaped curve with its peak at approximately noon.

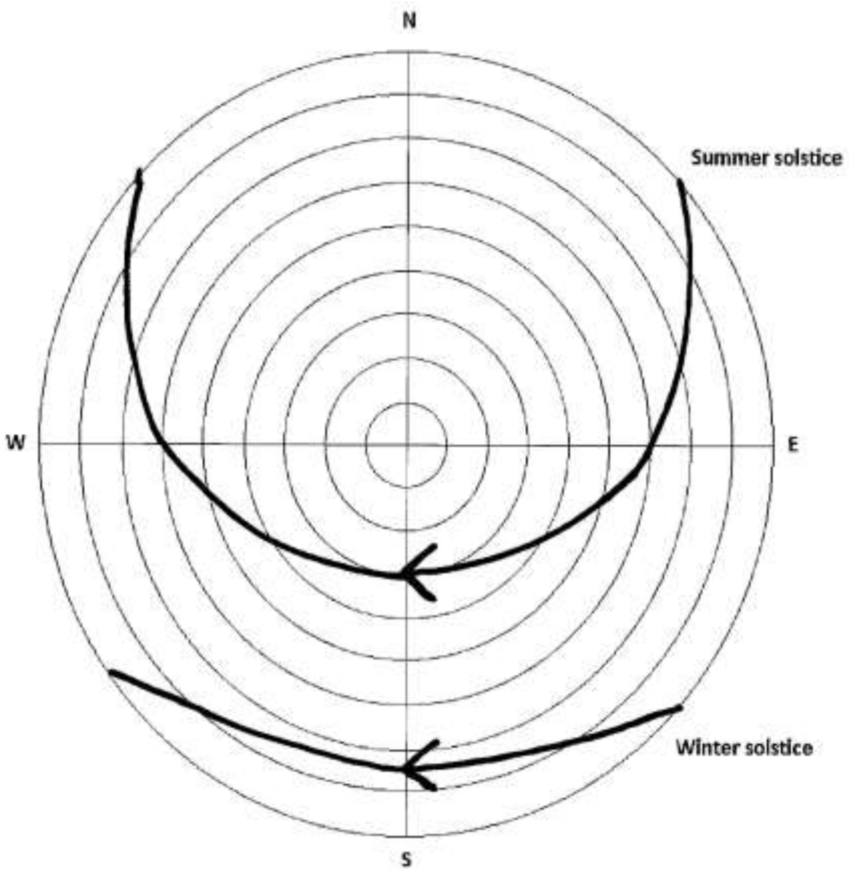

Figure 1-d Azimuth plots showing solar path and both summer and winter solstices in London, UK.

1.4.5 Effect of altitude

Higher UV levels are found at altitude due to low atmospheric pressure (section 1.4.1) and less atmospheric scattering. Additionally, less scatter is present due to the lower amounts of aerosols at altitude (Ambach et al, 1993). Blumthaler et al (1997) measured the increase due to altitude of 18%, 9% and 8% per 1000 m for erythemal UV, UVA and total irradiancies respectively (300 to 3000nm) in alpine areas although these figures may vary due to differences in atmospheric ozone and aerosols. Therefore the effect of altitude is likely to be lower in areas where there is less low altitude tropospheric pollution with higher amounts of atmospheric ozone above.

The effect of altitude is likely to be greater for shorter wavelengths due to their increased attenuation by tropospheric ozone at lower altitude (and higher atmospheric pressure) and a higher degree of scattering of shorter wavelengths. Altitude effect is stated to be higher by 2 to 5% per thousand metres at lower elevation angles in the winter. This is due to the path through the atmosphere being increased more at a low altitude site compared to an equivalent higher altitude site (Blumthaler et al, 1997).

1.4.6 Effect of cloud

Maximum exposures at ground level are generally seen on a clear day. The presence of cloud obscuring the solar disc will cause a reduction in the radiation received. It has been observed that levels of UVA and UVB may be enhanced from reflection from the side of clouds which are close to the line of sight of the sun (Lubin and Frederick, 1991). Maximum enhancement has been reported to occur with cumulonimbus clouds (Thiel et al, 1997) when the solar disc is not obscured (Estupinan at al, 1996) and when cloud position is between 60-75° from the sun (Weihs et al, 2000b).

Satellite studies have shown differences in backscattered radiance from high and low altitude clouds (Wen & Frederick, 1995). The thickness of the cloud layer also affects the degree of scatter and reflection of radiation (Kuchinke & Nunez, 1999). A study capturing measurements in Australia (McCormick & Suehrcke, 1990) found increases of up to 30% due to cloud with the greatest effect in the 350-400nm UVA range. Studies generally aim to assess the effect of cloud to the observer on the ground. The consideration for the pilot operating at altitude is the potential presence of a cloud layer below the aircraft.

Sabburg et al (2001) reported that enhancements of UVA were most likely in conditions of haze, light textured or cumulus cloud partially covering the solar disc. It was postulated (Sabburg and Wong, 2000) that this effect was due to refraction and scattering of direct sunlight through haze or high altitude cloud and forward scatter from edges of low altitude cloud. The effect may therefore be greatest where multi-layer clouds are present (Krzyscin et al, 2003).

Based on ground studies, it is likely that in addition to the effect of altitude, UV levels reaching the aircraft will be further increased by reflection from cloud top particularly where there are clear skies or thin high altitude cloud conditions above the aircraft. Total UV exposure is likely to be a combination of direct radiation from the sun, reflection from cloud and ground and scattered UV from cloud and atmosphere.

1.4.7 Units of measurement

There are a number of radiant and photometric measures used in this research. Radiant measures are derived from spectrometer measurements (chapter 5) and are used to describe UV and blue light hazard exposures. Where appropriate, action spectra (section 1.4.8) are applied to the data.

Radiance is a measure of the power or radiant flux (W) per unit solid (radian) angle and per unit projected area. Its unit is W sr^{-1} m^{-2} and it is used for retinal blue light hazard exposure calculations. Irradiance is incident power (W) per unit surface area (W m^{-2}). Irradiance for a narrow spectral band (spectral irradiance) per wavelength interval is defined as W m^{-2} nm^{-1}. Radiant exposure is incident energy (radiant flux per unit time or joule) divided by surface area of receptor and is measured in joules (J) per square metre (J m^{-2}).

Illuminance is a photometric measure which applies the $V(\lambda)$ function to radiant flux (lumen) to account for the ocular sensitivity to different wavelengths of visible light. Illuminance is lumen (lm) per unit surface area (lm m^{-2}).

A minimal erythemal dose (MED) is an erythemally weighted measure of radiant exposure of UVR required to produce a barely perceptible erythema. It is influenced by a number of factors, particularly skin type and susceptibility to sunburn. A standard erythemal dose (SED) is also an erythemally weighted measure of radiant exposure and 1 SED is defined as 100 J m^{-2} (World Health Organisation, 2006).

1.4.8 Action spectra

An action spectrum provides the relative damaging effect of radiation at different wavelengths for a particular biological process. A number of action spectra have been formulated including the blue light hazard spectrum, erythemal action spectrum and the actinic UV action spectrum.

The blue light hazard action spectrum has a peak action between 435-440nm where it is normalised and its maximum effect set at 1.0. The spectrum is applied between the range 300-700nm and has values of 1×10^{-2} between 300-380nm and 1×10^{-3} between 600-700nm. The International Commission on Illumination (CIE) erythemal action spectrum is normalised (1.0) from around 240 to 300nm for erythema in humans (ICNIRP, 2004). Within the UVA range, the action spectrum varies from 1×10^{-3} to 1×10^{-4} although Anders et al (1995) found a second maximum in erythemal action spectrum at 362nm at lower relative response than first maximum within the UVB range.

The actinic UV (200-315nm) action spectrum (International Radiation Protection Association, 1989) has been used for assessing the effect of UV on human skin and eyes. The action spectrum is normalised at 270nm and has been used to calculate UV exposure limits to skin and eye.

Further action spectra have been formulated for photoconjunctivitis (CIE, 1986a) and photokeratitis (CIE, 1986b). Photobiologically damaging UV for photokeratitis does not extend into UVA. With the exception of the blue light hazard, action spectra have higher effectiveness in the UVB range.

There is no commonly used action spectrum for melanoma in humans (Parisi et al, 2004). Evidence from animal models and human use of sun beds implicates UVA in the pathogenesis of melanoma (Wang et al, 2001). A review by Mitchell and Fernandez (2012) suggest that only UVB is capable of initiating melanoma and that both UVA and UVB are involved in the disease progression. There is evidence that sunscreen users have a higher melanoma risk (Autier et al, 2011). It is postulated that the cause is due to the use of sunscreen blocking UVB preventing sunburn but extending the user's sun exposure for getting a tan which causes an increase in UVA exposure. A UVA mediated process has also been suggested in the formation of non melanoma skin cancers (Bachelor and Bowden, 2004).

1.4.9 Global solar UV index and ocular exposure

The global solar UV index is a scale which describes the level of solar UV radiation in an outdoor location on the Earth's surface (World Health Organisation, 2002). The scale has been developed to help understanding within the general public of the risks of excess UV exposure, and to encourage the use of protective measures when exposed to UV.

Solar UV levels are not related to temperature and it is not possible for humans to feel UV radiation during exposure. The heat often felt when sunbathing is due to longer wavelengths (infrared radiation). Excessive exposure to UVB is associated with sunburn which is seen within the erythemal action spectrum.

Around midday, when there is least atmospheric scattering due to the shorter path through the atmosphere, there will be a higher level of UVB and a higher UV index. At lower elevation angles (as found for example during mid morning and afternoon), a greater proportion of UVB is scattered in the atmosphere, giving a lower level erythemal UV and a higher relative proportion of UVA.

Greater ocular exposures are likely where the elevation angle is not at its daily maximum. It has been argued (Citek et al, 2011) that mid morning and mid afternoon periods are when ocular exposure is likely to be greatest as, due to the human anatomical structures of the brow, a greater degree of natural protection is afforded from an overhead sun. Additionally, a slight stooped posture adopted by humans when walking (Sasaki et al, 2011) allows further ocular protection from solar radiation. Above an elevation angle of 40°, ocular UV exposure is reported to decrease rapidly (Sasaki et al, 2011) with remaining exposure being caused by scattered and reflected radiation (Citek et al, 2011).

In the context of the pilot, global solar UV index would not be the optimum measure of non-ionising radiation risk to ocular damage. As discussed in section 1.5.1, a large elevation angle around noon is more likely to cause the sun to be obscured from the pilot by the aircraft structure. Parisi and Kimlin (2000) measured UVA dose in different seasons in a vehicle and found highest exposure in March (Autumn, Australia) due to a lower elevation angle. In summer months, more UVA was blocked by the roof of the vehicle.

Pilot ocular exposure will be affected by radiation being filtered as it passes through the aircraft windshield. Finally, as the pilot adopts a seated position during flight and is positioned at a slight positive angle due to the attitude of the aircraft (section 1.5.2), the role of anatomical features in UV protection is likely to be reduced.

1.4.10 Personal factors

Although exposure to UV (optimum waveband 295 – 315nm) is required to aid the production of vitamin D (Bendik et al, 2014), there are a number of individual factors which influence the risk of excess exposure to UV radiation. The large population variation of skin pigment has led to the development of a classification system (Fitzpatrick, 1986) to aid exposure limit for various skin types. The lower exposure thresholds in light pigmented skin types is also reported for ocular damage in individuals with lighter coloured irides (Ham & Mueller, 1989) however there is likely to be a large overlap in these groups as a greater proportion of blue eyed individuals will have lighter skin tone. Wang et al (2003) found no association between iris colour and early or late age-related macular degeneration (AMD).

Retinal exposure is likely to decrease with age due to a concurrent decrease in pupil size over a wide range of illuminance levels (Winn et al, 1994) and lenticular changes which selectively absorb shorter wavelength visible light (Sliney, 2002). Personal strategies for protection from UV exposure include the application of sun cream and the use of a hat, sunglasses or UV blocking contact lenses. There is limited evidence (Kronschlager et al, 2013) that caffeine eye drops can be effective in protecting the eye against UV damage.

A number of drugs including tetracycline, amiodarone and chlorpromazine are known to have side effects associated with a risk of increased photosensitivity. These can cause phototoxic or photoallergic skin reactions following UV or visible light exposure (Drucker & Rosen, 2011) however they are not reported to cause ocular damage due to photosensitivity effects. There is increasing evidence that dietary intake of certain anti-oxidants can offer increased protection against the blue light hazard. This is discussed in section 2.5.

Finally, the pilot can control the ambient temperature in the cockpit and were skin damage to be occurring in flight, a lower temperature could result in a reduced thermal discomfort and an increased ability to remain in that environment for longer without any subjective symptoms.

1.5 Considerations for professional pilot exposure

1.5.1 Ergonomics and the visual piloting task

The pilots' visual task is complex as they are surrounded by the tools required to interpret flight information and manage the flight of the aircraft. Generally, the primary flight instrumentation is duplicated and situated in front of each pilot below the horizontal sight line and protected to a degree from sunlight by a cowling or ledge protruding at a level just below the windshield toward the pilot.
Engine and fuel management systems together with communication systems are usually located between the pilots extending from next to the primary displays downwards in a horizontal panel situated between the pilots' seats.
Flight controls are present either in front of the pilot as a traditional yoke stick such as typically found in Boeing aircraft (Figure 1-e) or as a joystick control situated to the side of the pilot as typically found on Airbus aircraft (Figure 1-f).

Figure 1-e Typical Boeing cockpit

Figure 1-f Typical Airbus cockpit

Overhead panels often contain warning systems, pilot preference settings and circuit breaker systems and are generally not required routinely during flight (Figure 1-g). Emergency oxygen systems are generally located nearer the pilots' side window and toward the rear of the seat.

Figure 1-g Typical overhead panel information

The level of irradiance to which a pilot can be exposed during flight is limited by the structure of the aircraft and the size and position of the windshields. An observer on the ground with no obstacles or highly reflective surface nearby would expect to receive a peak erythemal irradiance around noon. However for the pilot, the sun at noon is more likely to be obscured by the aircraft structure, particularly during summer months in the northern hemisphere. The peak irradiances that occur in flight are likely to be driven more by the position of the aircraft in relation to the sun.

1.5.2 The pilot operational environment

Section 1.4.1 describes the reduction of atmospheric pressure with altitude. Aircraft systems use this reduction in pressure to display altitude information to the pilot. However atmospheric pressure is strongly influenced by weather conditions. An aircraft flying from one point to another is likely to pass through fluctuations of the Earth's atmospheric pressure. This in turn would cause inaccuracies in altitude display. In order for all aircraft operating within the same vicinity to display the same altitude setting, a standardised system is adopted above a safe height (transitional altitude) from the ground where a mean sea level atmospheric pressure of 1013.2 millibars (mb) is adopted. An altitude is then described as a flight level or FL. FL350 corresponds to an altitude of 35,000 ft above mean sea level using a 1013.2mb pressure setting.

Aircraft operations additionally adopt a FL height rule dependant on the direction of travel of the aircraft. This ensures safe vertical separation of aircraft and means that an aircraft returning to base on a two sector flight will be at different FL on the inbound sector compared to the outbound. Generally, unless operating above FL410, flights with an eastbound component use a FL with an odd second digit (such as FL 310, 330) and flights with a westbound component use a FL with an even second digit (such as FL 320, 340). Aircraft require clearance from air traffic control to a particular FL and may be restricted to a lower FL where air traffic is busier above.

For the purposes of this study, cruise altitude is considered the point at which the aircraft has reached its permitted FL and has achieved level flight. It is recognised that this results in variations between flights in the actual altitude above sea level. Commercial aircraft generally follow a series of airways en route to the destination. These are set 'lanes' in the sky a certain distance wide and are generally in a straight line between ground navigational beacons. The aircraft's navigation system can be set to identify and track in the direction of a ground beacon. Aircraft with autopilot can be programmed by the pilot to follow a series of ground beacons. This results in a cruise flight with a series of generally small changes of direction of heading during flight. The wind speed and direction also affects the direction in which the aircraft nose points. In order to track to a target point in a straight line, a small change of aircraft heading would be adopted that points the nose towards any oncoming wind.

Most commercial jet and turboprop aircraft types generally adopt a slight nose up attitude for stable cruise flight. This angle does vary between aircraft types but is generally around 2°. This, together with the changes of heading during flight will affect the relative position of the sun to the pilot.

1.5.3 Flight profiles, pilot flying hours and career length

Flight profiles can be defined for each aircraft type although they vary considerably dependent on a number of factors including aircraft configuration, weight and power settings (Civil Aviation Authority, 1992). However with improvements in aerodynamics and efficiency of engine units, modern aircraft types are generally able to achieve a higher cruise altitude at a faster rate than their older aircraft type counterparts. In addition to a fuel saving benefit, this can also result in longer flight times. This in turn may result in the pilot of a new aircraft design being able to spend a larger proportion of a flying career at cruise altitude.

Professional pilots cannot log more than a maximum of 900 hours per annum (Civil Aviation Authority, 2003). The mean pilot flying hours per annum will be less than this. Clearly, for the purposes of solar radiation exposure, only those hours flown during daylight hours can contribute to the pilot's annual occupational dose. The typical flying schedules of a number of operators involved in this research are described in section 10.5.

There is some anecdotal evidence that the choice of professional flying as a second career is less common than in previous decades. This may to be due to a number of factors including the significant investment in flying training, the lack of airline funded training schemes and the uncertainty of securing airline employment after training in the current industry climate. Applicants for professional flying training are often school leavers or university graduates. Beyond the age of 65, pilots are not able to fly an aircraft engaged in commercial air transport (Civil Aviation Authority, 2013). The minimum age for holding an airline transport pilots licence is 21 (Civil Aviation Authority, 2007). Pilots can therefore achieve up to a 44 year long airline career.

It is feasible that daytime long haul flights could expose airline pilots to high light levels for prolonged periods of time particularly when 'chasing the sun', flying east to west during daylight hours.

1.5.4 General windshield properties

There are a number of requirements for aircraft windshields. The windshields on the majority of commercial air transport aircraft which have pressurised cabins must be able to withstand the effects of continuous and cyclic pressurization loadings and the effects of temperatures and temperature differentials at altitude. The windshield and side windows must be capable of withstanding the maximum cabin pressure differential loads together with the critical aerodynamic pressure and temperature effects after any single system failure (Federal Aviation Administration, 2003). In the case of a single failure that is obvious to the flight crew, the cabin pressure differential is reduced from the maximum, in accordance with appropriate operating limitations, to allow continued safe flight of the airplane with a reduced cabin pressure altitude.

All internal panes must be made of non splintering material and windshield panes directly in front of the pilots must be able withstand, without penetration, the impact of a four-pound bird during cruise flight (Federal Aviation Administration, 2003). The windshield panels in front of the pilots must be arranged so that, assuming the loss of vision through any one panel, one or more panels remain available for use by a pilot to permit continued safe flight and landing (Federal Aviation Administration, 2003).

Typical designs of windshields and cockpit side windows are laminated multi-plied constructions, consisting of at least two structural plies, facing plies, adhesive inter layers, protective coatings, embedded electro-conductive heater films or wires, and a mounting structure. Typically, the structural plies are made from thermally or chemically toughened glass, or transparent polymeric materials such as polymethylmethacrylate (acrylic) and polycarbonate. These plies may be protected from abrasion, mechanical, and environmental damage by use of facing plies together with protective coatings. The facing and structural plies are laminated together with adhesive interlayer material of poly-vinyl butyral (PVB), polyurethane, or silicone (Federal Aviation Administration, 2003).

In order to keep window areas free of ice and frost, window anti-icing, de-icing and de-fogging systems are used. The systems vary according to the type of aircraft and its manufacturer. Some windshields are built with double panels with a space in between, which allows the circulation of heated air between the surfaces to control icing and fogging. Others use windshield wipers and anti-icing fluid, which is sprayed on (Federal Aviation Administration, 1976). Many windshield designs have an external hydrophobic coating.

1.5.5 Optical transmission properties of windshields

The factors that may influence the optical transmission profile of a windshield include the type of windshield design, number of laminate plies and inter layers and their optical properties, the material used for the de-icing heater element and the number of elements used. It is not known whether age would influence the optical transmission. Cockpit windshields are assessed at periodic maintenance and replaced if de-lamination, abrasion or heater element problems are detected. The only optical transmission requirement is for a minimum transmission of the total visible light (personal communication, A Goudie 01/12/09).

Parisi et al (2004) report that UVB transmission is affected by the thickness of the material however for UVA, less than 5% difference in transmission was present between thin and thick glass. Therefore, the ratio of solar UVB/UVA is significantly affected once filtered through glass, particular when it is of greater thickness. The authors also state that erythema can be experienced due to filtered solar UV if the exposure period is sufficiently long enough.

1.5.6 Position of windshields & incident angle of light

Data were obtained from Airbus A320 and A330 aircraft characteristics manuals (Airbus, 2012; Airbus, 2014) and are presented as these aircraft types were both used for in flight data collection in chapter 6. These data present the binocular visibility through the aircraft windshield from the captain's eye position and reveal the maximum angle subtended at the eye from the windows. From these data, estimates can be made as to the relative angles up to which the solar disc would be directly visible to the pilot during flight. Clearly, the windows nearest the pilot cause the largest angular effect. Data of the angle subtended by the windshields on the opposite (first officer) side of the cockpit are given for Airbus A320 data. The data from the right hand seat would be symmetrical to that of the left hand (captain's) seat. Data from A320 and A330 are shown in Figure 1-h and Figure 1-i respectively.

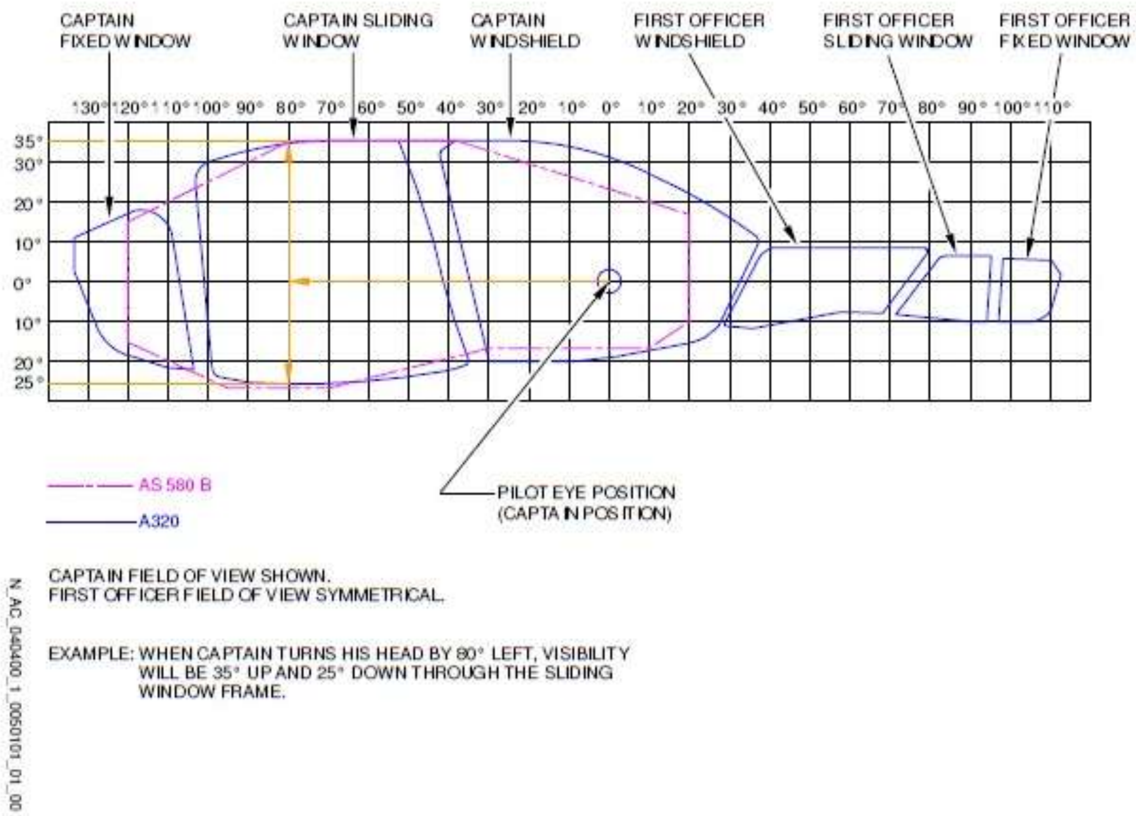

Figure 1-h Airbus A320 pilot field of view diagram. Taken from Airbus A320 specification manual.

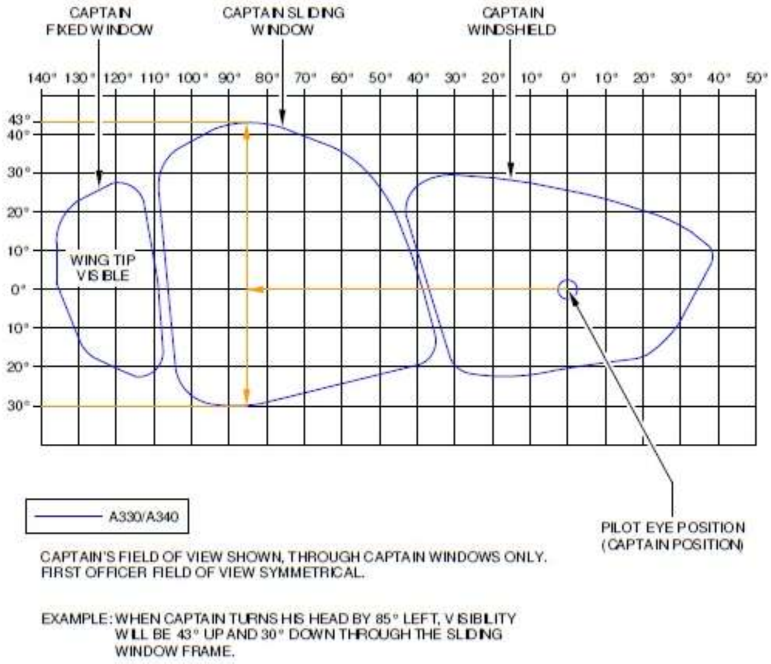

Figure 1-i Airbus A330 pilot field of view diagram. Taken from Airbus A320 specification manual.

No data were available for Boeing aircraft and it is not known to what extent other passenger fixed wing aircraft would differ from those presented above. Additionally, the data assume that no visors or blinds (section 1.5.7) are in use.

Due to aerodynamic and impact resistance considerations, windshields are positioned at an angle away from normal to the direction of travel of the aircraft. This, together with the angle of the sun on the windshield which will vary as the aircraft travels, will affect the degree of UV attenuation through the windshield.

1.5.7 Standard aircraft fitted sun protection systems

Most modern transport aeroplanes have systems to protect the pilot from bright sunlight on the flight deck. In addition to the design and placement of instruments to ensure optimum legibility, aircraft have visors and blinds which the pilot can deploy to cover the window areas. Figure 1-j shows a diagrammatic summary of an Airbus cockpit with the positions of the visors and blinds.

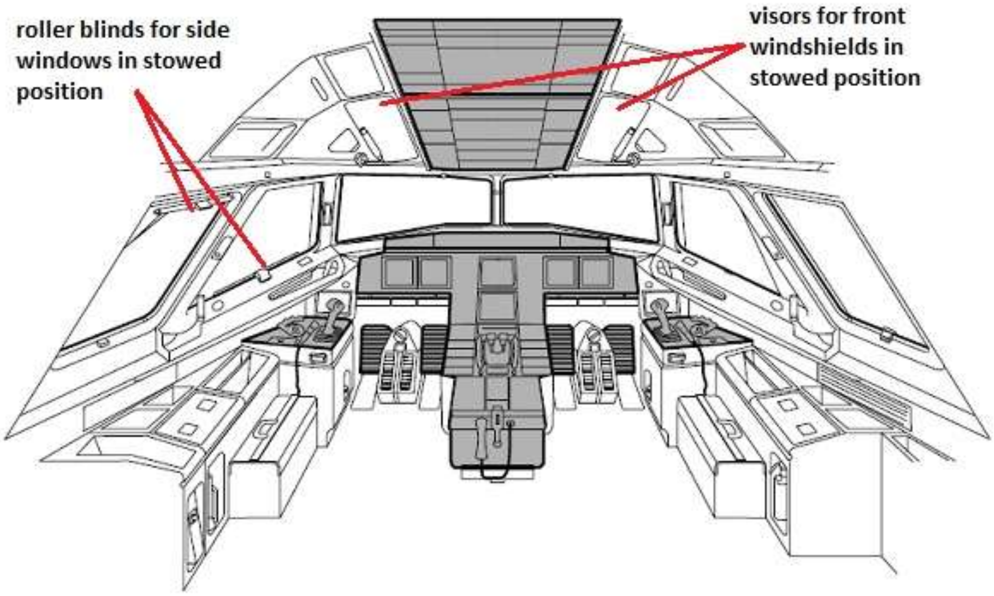

Figure 1-j Diagrammatic illustration of Airbus A320 cockpit showing positioning of front visors and side blinds. Adapted from Airbus A320 manual.

There are several manufacturers of both aircraft visors and side blinds. The front visors are similar to a vehicle windscreen visor except that they consist of a dark tinted plastic material (Figure 1-k) which strongly attenuates radiation (see section 8.3 for measurements) as opposed to the typical car sun visor which is comprised of a non transparent material.

Figure 1-k Typical front visor. Taken from guanyiareo.com (Guanyi Aero, no date).

When deployed, the visor has a degree of manoeuvrability so that it can be adjusted to attenuate sunlight. There are generally two designs of front visor. Those which are adjusted by a swivel ball joint (Figure 1-k) at its fixing point to the aircraft (generally found on Airbus aircraft) or those which are stowed separately and attached, when required, to a fixed rail above the windshield (generally found on Boeing aircraft). Front visors cover only a proportion of the total front windshield area.

Roller blinds are made from a thin flexible material and are stowed within a spring mechanism cylinder. They are deployed from either top or bottom of the side window and are secured by attaching the leading edge to a clip on the opposite end of the window. The blinds are either a fixed width (Figure 1-l) or shaped to a particular window (Figure 1-m). Side blinds offer a greater coverage of window area compared to the front visors.

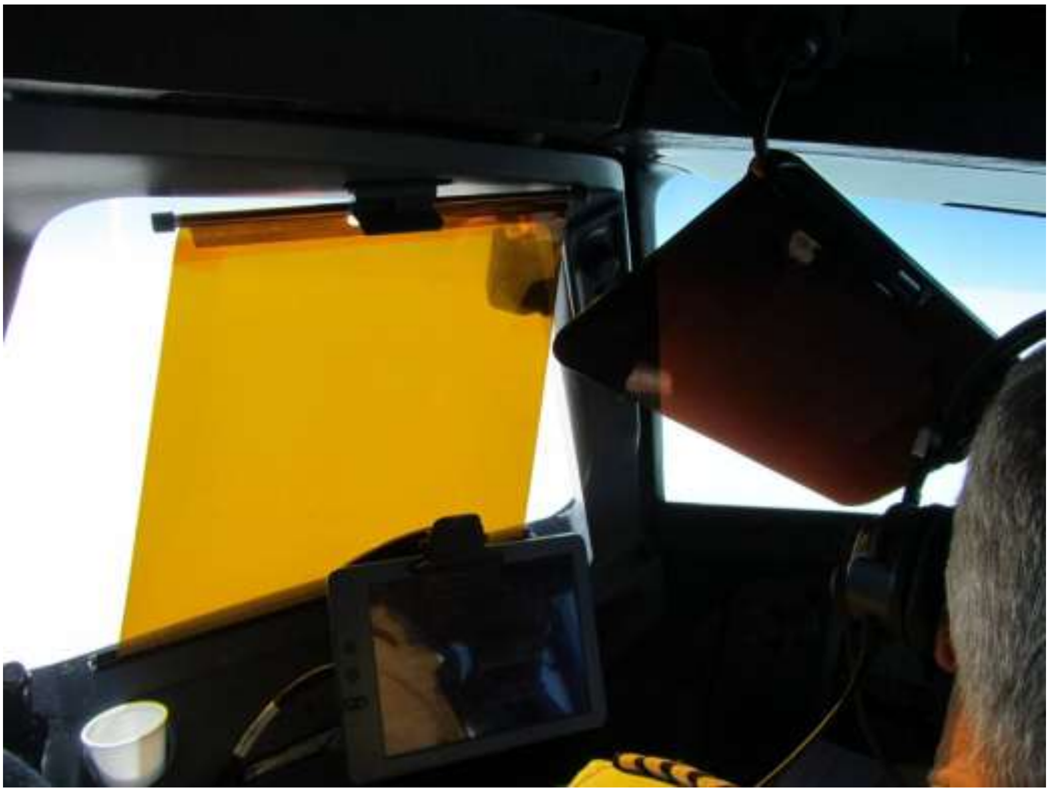

Figure 1-l Airbus front visor and side roller blind in use. Roller blind is of constant width.

Figure 1-m Roller blind tailored for a particular window shape. Taken from guanyiareo.com (Guanyi Aero, no date).

Some manufacturers of visors and blinds provide information of the degree of UV attenuation offered (Aeroshade Technologies, no date). Generally, more emphasis is placed by manufacturers as to IR attenuation and the heat reflecting properties of the materials (Areoshade Technologies, no date; Eire aviation Inc, no date) to improve comfort.

Helicopters do not generally have the same level of standard fitted visor protection afforded. From the author’s discussion with several helicopter pilots, larger helicopters may have front visors fitted but not side roller blinds.

Separate stick-on visors are available to pilots through several retailers (mypilotstore, no date; Transair flight equipment, no date). These attach directly to the inside of the windshield and can be used in addition to standard fitted sun protection systems.

1.6 Pilot medical certification

All pilots must hold a current valid medical certificate in order to exercise the privileges of their aviation licence. There are two main classes of medical certificate which are Class 1, required for all professional flying including airline, cargo, commercial helicopter flying, police helicopter, air ambulance, aerial work (such as surveying or photography) and instructing. Class 2 medical certification is used for pilots flying recreationally (aeroplanes or helicopters) on a private pilot's licence. Revalidation medical examinations are required routinely for ongoing certification. The period of time between examinations is dependent on the pilot's age and class of medical held (Civil Aviation Authority, 2012).

Various conditions can be placed on a medical certificate which is then only valid when the pilot meets these requirements. For instance, where the pilot's distance vision unaided falls below the minimum standard, the pilot has a VDL limitation placed on their certificate which states that corrective lenses must be worn and that a spare pair of spectacles must be carried. For the presbyope, all spectacles must be multifocal (bifocal, trifocal or progressive). A pilot using contact lenses may use these as their primary correction and must carry a spare pair of spectacles. Guidance currently states that one pair of spectacles must be untinted, whilst the second pair can be prescription sunglasses (Civil Aviation Authority, no date).

A pilot with distance vision that falls within limits unaided but who is presbyopic and does not meet the intermediate (N14 at 1m) or near (N5 between 30-50cm) requirements is required to have available appropriate near vision correction in a narrow look-over frame style. A VNL limitation would be required on the pilot's medical certificate.

The UK CAA is a member of the European Aviation Safety Agency (EASA) and applies, together with all other European states, harmonised medical standards and requirements. EASA medical requirements were implemented in 2012 replacing the previous Joint Aviation Regulations (JAR) which, in turn were implemented in 1999. These changes and subsequent amendments have resulted in a gradual relaxation of the maximum limit on spectacle lens power allowable over the past 15 years for both Class 1 and Class 2 medical certification. As a result, a higher proportion of ametropes may now be eligible for certification and it is speculated that this in turn may increase the percentage of UK certified pilots with a VDL limitation on their medical certificate.

1.7 Ocular absorption of UV radiation

The ocular absorption varies with structure and wavelength. All radiation below 280nm is absorbed by the cornea (Figure 1-n). At increasing wavelengths, an increasing proportion of incident radiation is transmitted through the cornea and absorbed within the aqueous, lens or vitreous. At 380nm, 80% of radiation is transmitted through the cornea (World Health Organisation, 1993). The lens absorption is strongest within the 340-380nm range and lenticular UV transmission decreases steadily with age (World Health Organisation, 1993).

It is reported that approximately 1% of solar UV radiation reaches the retina (Sliney, 2002) however this value is likely to be affected where the incident radiation has already been filtered by materials such as a windshield.

The removal of the lens as occurs in cataract surgery has the potential to cause an increase in UV reaching the retina. However, surgery generally involves replacement of the cataract with an intraocular lens (IOL) implant. The material can be designed to ensure good UV blocking properties and a UV blocking IOL has become an internationally accepted standard (Augustin, 2014). There has been more recent interest in ensuring that IOLs also have good blue light blocking properties however the potential detrimental effects to scotopic vision and circadian rhythm have been highlighted (Mainster and Turner, 2010; Yang and Afshari, 2014).

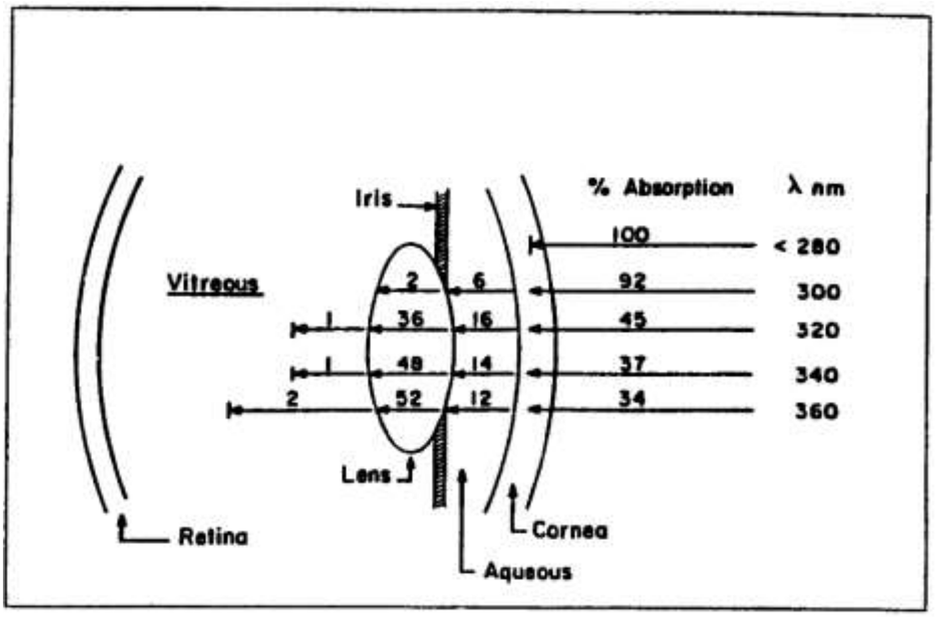

Figure 1-n Percentage of absorption of UV by various ocular structures. Taken from 'How light reaches the eye and its components' (Sliney, 2002).

1.8 ICNIRP guidelines for exposure

The International Commission on Non-ionising Radiation Protection (ICNIRP) has published a series of guidance material documents describing ocular and skin exposure limits to UV, incoherent visible and infrared radiation (ICNIRP, 2004; ICNIRP, 2013). These recommendations are for general use and were not specifically aimed at pilots. The publications recommend exposure limits based on scientific evidence and describe the considerations and factors affecting exposure calculations. An exposure per event or repeated exposures below maximum levels set in ICNIRP would not be expected to cause adverse effects (ICNIRP, 2004).

1.8.1 UV

The guidelines on exposure limits for UV (ICNIRP, 2004) refer to radiation between 180 to 400nm. Spectrally weighted radiant exposure to the unprotected eye should not exceed 30 J m^{-2} and for wavelengths between 315 to 400nm, the unweighted total UV radiant exposure should not exceed 1 x 10^4 J m^{-2} within an 8 hour period. ICNIRP (2004) state that the exposure limit should be considered an absolute limit for direct exposure of the eye. The guidelines recommend protection from solar UV including hats and eye protection.

1.8.2 Blue light

Within the visible and infrared radiation guidelines, the areas of ocular insult covered include thermal damage of the cornea, iris, lens and retina (all affected by longer wavelength visible and infrared radiation) and photochemical damage to the retina from blue light. This photochemical damage is caused principally by wavelengths within the 380-550nm range and within a 300-550nm range for the aphakic eye with no natural crystalline lens or IOL in place. This type of damage is known as type II photochemical damage (section 2.5) and has been demonstrated with shorter exposures, generally up to around two hours (Ham et al, 1976; Ham et al, 1980; Lund et al, 2006). Photochemical retinal damage caused by lower level exposure and a broadband source such as the sun generally occurs with shorter wavelengths and longer exposure times than thermal damage (ICNIRP 2013).

The peak of sensitivity to the blue light hazard is around 440nm (Algvere et al, 2006). Exposure is affected by both irradiance and exposure duration and the Bunsen-Roscoe reciprocity law is applied, therefore high irradiance for short duration has a similar effect to a lower irradiance over a longer duration for the purposes of comparing to ICNIRP limits. The ICNIRP recognise that there is a lack of data for determining long term chronic exposure and guidelines are based on threshold limits following a short delay (up to 48 hours) for onset of damage. Long term exposures are discussed in section 2.6.

In order to calculate the most accurate hazard assessment and to derive biologically effective radiance or irradiance, an appropriate action spectrum provides weighting (ICNIRP, 2013). With a broadband optical source (such as the sun), a series of action spectra may need to be applied. For the purposes of this study, the aphakic hazard function is not considered. Additionally, analysis has not been conducted investigating the risk of thermal retinal injury involving exposure to longer wavelength visible and infrared (IR) radiation.

The ICNIRP exposure limits factor for any enhancement of photochemical effects with additional thermal effect by using a greater reduction factor incorporated into the limits (ICNIRP, 2013). The ICNIRP limits are set to a level below known damage thresholds and include a reduction factor of at least 2. The probability of damage as a function of dose is assumed to be a normal distribution. The dose threshold stated is the effective dose to produce a 50% probability of damage (24hr after exposure for overall retina or 1hr for macula). The guidelines also make the assumption that most outdoor exposures would involve off-axis or indirect sources which would not be hazardous to the eye except potentially in environments with high surface reflection such as snow or water.

The ICNIRP guidelines recognise that disability glare, discomfort glare (see glossary) and after images may be caused by exposure to bright light sources below exposure limits. The presence of these symptoms does not indicate exposure beyond safe recommended limits. The current guidelines do not address the effect of the impact of light exposure to the circadian rhythm.

The basic exposure limits are based on a 3mm pupil. Other variables affecting retinal exposure such as focal length and clarity of media have been taken into account in deriving recommended exposure limits. It is also recognised that natural aversion responses during longer exposures to bright light include voluntary eye and head movements which distribute light energy over a larger area of the retina. Normal eye movements will enlarge the irradiated retinal area and increase angular distribution of energy. However, this effect is greater in the presence of a smaller retinal image size and has less effect in an unrestricted field.

Blue light exposure is cumulative. For exposure times up to 10,000 seconds (approximately 2hrs 47min), the blue light weighted effective radiance dose limit is 1 x 10^6 J/m^2.sr, e.g. for continuous uniform exposure longer than 10,000 seconds, the blue light weighted effective radiance should not exceed 100W/m^2.sr. For the radiance dose for exposures longer than 10,000 seconds, ICNIRP state that it is not necessary to consider the added radiant exposure or radiance dose and that it can be treated as a series of independent exposure episodes although in cases of irregular exposure, the time axis should be positioned to give a maximum possible dose calculation.

1.9 Health and Safety legislation & optical radiation at work

There are a number of acts implemented which aim to ensure the health and safety of employees at work. The Health and Safety at Work Act (Great Britain, 1974), sets out general duties that employers have towards their employees and requires the employer to reduce risk as far as reasonably practical. The Management of Health and Safety at Work Regulations (Health and Safety Executive, 1999) provides further detail as to the identification of health and safety risks at work and requires employers with five or more employees to conduct a risk assessment. Risk assessments are usually basic unless there is deemed a potentially serious hazard such as in a nuclear or chemical plant. This legislation enables the majority of employers to comply with the legislation without undue time or cost. The Health and Safety Executive (2010) provide guidance, codes of practice and, where a risk is deemed to be great, regulations to ensure the health and safety of employees.

The Control of Artificial Optical Radiation at Work Regulations 2010 requires employers to assess the level of radiation to which workers are likely to be exposed, to reduce exposure risks and to provide training to workers (Health and Safety Executive, 2010). These regulations do not apply where radiation received is from a solar source.

The Civil Aviation Authority (CAA) is the UK specialist regulator for the aviation industry and regulates to ensure safe operation and maintenance of aircraft and sets the licensing standards and training requirements for pilots and air traffic controllers. The Aviation Health Unit (AHU) within the CAA Medical Department aims to provide information for health professionals, air crew and passengers on the health aspects of air travel.

The issue of pilot ocular exposure to non-ionizing radiation during flight is unlikely to be considered a serious hazard under Health and Safety law and would therefore not involve a detailed risk assessment. Although not directly within a CAA regulatory framework, this issue could fall within AHU remit although no AHU publications on this subject currently exist.

1.10 Types of sunglasses

Sunglass lenses are manufactured from either glass (such as crown glass) or plastic materials (such as acrylic; which is used most commonly). Different colour tints will have different spectral absorption profiles and darker tints will absorb a greater percentage of incident visible light. A tint may be manufactured to selectively absorb certain wavelength bands. Graduated tints are darker at the top of the lens, and lighter at the bottom of the lens. Tints are generally applied by dipping lenses into a hot coloured dye (Wilkinson, 2006).

Photochromatic lenses darken when exposed to UV and sometimes, to a lesser extent, to visible light (Transitions Optical, 2013). They may be manufactured from either glass or plastic materials. Polarised lenses offer absorption of visible light and reduce glare from light reflected off surfaces such as water.

There is a wide variation in sunglass frame styles although sunglasses should generally be of a sufficient frame size to offer protection from peripheral radiation which may reach the eye via a number of different routes (Figure 1-o).

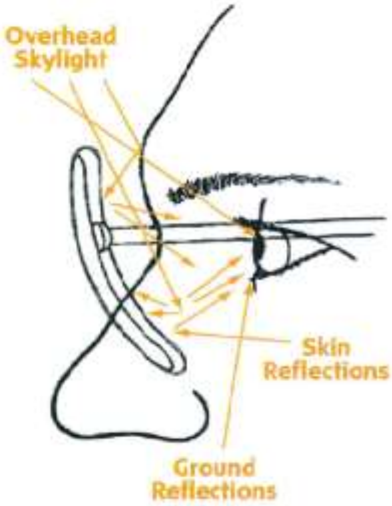

Figure 1-o Various ways in which the eye can be exposed to peripheral radiation. Taken from 'The eye and solar ultraviolet radiation' Citek et al, 2011.

An increase in UV exposure has been suggested (Citek et al, 2011) when wearing sunglasses with poor peripheral protection as a reduction in squinting reflex and an increase in pupil size may occur. Therefore, wrap around style sunglasses, such as Oakley (Figure 1-p), are likely to provide optimum protection from peripheral radiation.

Figure 1-p Typical wrap around frame style

1.11 Transmittance properties of lens materials

A degree of UV protection is offered from untinted lens materials. Crown glass blocks UV below 320nm whilst the commonly used CR39 blocks UV radiation below 355nm (Jalie, 2005). Commercially available polycarbonate lens materials are renowned for their impact resistance and effectively absorb UV below 385nm due to the addition of a chemical coating improving scratch resistance (Pitts, 1990). This material is less popular than CR39 in the UK as it has a lower optical quality (V-value) than CR39 and has poorer chemical resistance and higher susceptibility to cracking (Gilbert, 2014). Plastic lenses with a higher refractive index generally have better UV attenuating properties. More modern lens materials such as Trivex and Tribrid materials, manufactured by PPG Optical Products have effective UV absorption below 400nm and a higher V-value than polycarbonate (Gilbert, 2014).

Anti-reflection coatings are frequently applied to spectacle lenses. Lenses with these coatings transmit more visible light than their non-coated counterparts however they have been reported to reflect more UV radiation (Citek, 2008), which could increase ocular UV exposure if the source were behind the wearer and reflection occurred from the back surface of the lens. Manufacturers of more recent anti-reflection coatings claim blue light transmission reduction through a lens by the coating selectively increasing the reflection of short wavelength visible light (Nikon, 2012). If applied to both surfaces, an increase in exposure could also occur where the source is behind the wearer.

A number of contact lens manufacturers offer soft contact lenses with UV blocking properties. Contact lenses that offer UV protection are labelled as Class I or Class II. Class I offers the highest level of protection blocking over 90% UVA and 99% UVB radiation (Wolfsohnn, 2013), and is found in a number of silicone hydrogel lenses and in all contact lenses made by Johnson & Johnson (Acuvue brand) (Chandler and Nichols, 2011).

1.12 Requirements for sunglass filtering

The International Organization for Standardization (ISO) has introduced standards for sunglasses for general use (ISO 12312-1, 2013). This document is applicable to all non-prescription sunglasses and clip-ons for general use (including road use and driving) intended for protection against solar radiation; it does not include standards for specific sports eye protectors such as ski goggles or products intended for direct solar viewing (ISO FDIS 12312-2). Methods for testing sunglasses are detailed within ISO 12311. These documents provide more detail and guidance on measuring transmittance and explanation of errors to consider in testing and supersede the previous European standard EN 1836:2005 which set out recommendations for sunglasses.

ISO 12312-1 (2013) states that sunglass filters '*shall have no material or machining defects within the area of 30mm diameter around the reference point that might impair vision, e.g. bubbles, scratches, inclusions, dull spots, pitting, mould marks,* *notches, reinforced areas, specks, beads, water specks, pocking, gas inclusions, splintering, cracks, polishing defects or undulations*'.

Transmittance requirements are separated into five categories, dependent on the intended use and level of protection required. The requirements state that there should be no more than +/-2% overlap of the absolute luminous transmittance values (380-780nm) between categories 0,1,2 and 3. No transmittance overlap exists between categories 3 and 4. Table 1-b is adapted from ISO 12312-1 and summarises the transmittance requirements for general use sunglasses.

Consumer label	**Usage**	**Technical label**	**Requirements**			
			Ultraviolet spectral range		**Visible spectral range**	**Enhanced infrared absorption**
Descriptive label		Filter category	Maximum value of solar UVB transmittance (τSUVB) 280nm to 315nm	Maximum value of solar UVA transmittance (τSUVA) 315nm to 380nm	Luminous transmittance (τV) 380nm to 780nm	Maximum value of solar IR transmittance τSIR 780nm to 2000nm
Light tint sunglasses	Very limited reduction of sun glare	0	0.05 τV	τV	τV > 80%	τV
	Limited protection of sun glare	1	0.05 τV	τV	43%<τV<=80 %	τV
General purpose sunglasses	Good protection against sun glare	2	1.0% absolute or 0.05 τV, whichever is greater	0.5 τV Previously τV under EN1836	18%<τV<=43 %	τV
	High protection against sun glare	3	1.0% absolute	0.5 τV	8%<τV<=18%	τV
Very dark special purpose sunglasses	Very high protection against extreme sun glare, e.g. at sea, over snowfields, on high mountains, or in desert	4	1.0% absolute	1.0% absolute or 0.25 τV, whichever is greater Previously 0.5 τV under EN1836	3%<τV<=8%	τV

Table 1-b Summary of ISO 12312-1 sunglass transmittance requirements. Limits for UV and IR transmittance may be given as proportion of the filter's luminous transmittance. General purpose sunglasses are categorised as filter 2 or 3. Text in red highlights observed differences between ISO and previous limits under EN1836.

ISO specify limits on the uniformity of luminous transmittance (no greater than 10% relative to the higher value), except category 4, where no greater than 20% is allowed. For graduated tints, uniformity measurements are taken horizontally. For a photochromic lens, two transmittance values are used which correspond to faded and darkened states. For graduated tints, luminous transmittance is given from the reference point (as defined in ISO 4007). ISO 12312-1 also states a minimum polarizing efficiency for polarised lenses (categories 1,2,3 and 4), a minimum angle from the vertical plane and a minimum misalignment error between right and left lenses.

There is a requirement that there is no greater than 15% difference in luminous transmittance between right and left filters relative to the lighter filter. ISO 12312-1 (2013) sets a minimum allowable change of luminous transmittance following solar radiation. This is simulated by a suitable lamp for an irradiation time of 50 +/- 0.1 hours. In order to ensure that sunglasses do not impact on road safety, ISO specify additional requirements for sunglasses in categories 0,1,2 or 3 including minimum attenuation quotients for signal red (≥0.80), yellow, green and blue (≥0.60) and that luminous transmittance should be greater than 75% for twilight or night driving.

ISO 12312-1 does not contain a mandatory specification for blue light hazard protection. It states that: '*If solar radiation on the ground is evaluated with currently used limit values even under extreme illuminance conditions except for snow surfaces, an acute risk from exposure from the blue part of the spectrum is not to be expected'*. If a filter claims to have x% blue-light absorption, the solar blue-light transmittance should not exceed (100.5-x)% (ISO 12312-1, 2013).

In cases where it is claimed that a filter has x% solar UV, UVB or UVA absorption, the solar UV transmittance shall not exceed (100.5-x)%. Additionally, UV requirements must still be met and all claimed transmittance requirements must still be met. With regard to the UV risk, ISO 12312-1 acknowledge that although eyelid squinting reduces risk of exposure, '*sunglasses without side shields may permit peripheral exposure of biological significance due to the Coroneo effect*.'(CIT) This is also known as the Peripheral Light Focusing (PLF) effect and is discussed in section 2.4. There is also recognition that UV exposure is highly influenced by latitude, solar position and altitude however the UV transmittance limits aim to keep *“doses below recognised safe limit even for exceptional daily exposure except over snow”* (CIT). In order to do this, ISO have added additional safety margins for high exposure scenarios at mid-latitudes.

There are other worldwide sunglass standards which include the Australia/New Zealand standard (AS/NZ1067:2003) which has a mandatory product testing requirement. There is a proposal to alter these standards to bring them in line with ISO (personal communication S Dain, 29/04/14).

Additionally, the USA has sunglass requirements which are covered by the American National Standards Institute (ANSI) Z80.3-2010. These voluntary consensus standards include two transmittance categories. Class 1 lenses should have a minimum UVB (280-315nm) absorption of 99% and a minimum UVA (315-380nm) absorption of 90%. For Class 2 lenses, these absorption values are to 95% and 70% for UVB and UVA respectively (Citek et al, 2011). It is not known how these standards differ further from ISO or whether there are proposals to adopt ISO in the future.

1.13 Sunglasses marketed for pilots

A number of sunglass products are specifically marketed at the pilot population. Companies offering these products include ‘Bigatmo’, ‘Mile High’, ‘Randolph’ and ‘Caruso & Freeland’. Although all products should meet a minimum regulatory requirement as described in section 1.12, further marketing claims are made to attract the pilot customer. These can be broadly classified into additional lens sunlight filtering properties beyond minimum standards, protection from peripheral light and sunglass comfort.

1.14 Summary

There is good evidence that intensity of UV increases with altitude and levels can be elevated further under certain conditions in the presence of cloud. Pilot ocular exposure is likely to be affected by a number of factors including the position of the solar disc in relation to the aircraft, the altitude of the aircraft, the type of visual task being undertaken by the pilot, the transmittance of the windshield and the use of sun blocking strategies by the pilot. There are international guideline limits for ocular exposure to both UV and the blue light hazard. These are considered the most appropriate tool when considering exposure risk. Any sunglasses used by the pilot should conform to minimum international standards.

2. Chapter 2 Literature Review

CHAPTER OVERVIEW

This chapter provides a review of the literature surrounding the ocular effects of UV and blue light, particularly with regard to long term exposure and the effect of repeat and cumulative dose. The evidence concerning radiation related ocular pathology in pilots will be investigated together with the evidence underpinning sunglass recommendations to pilots. Studies of in flight measurements of UV and blue light and the transmission of aircraft windshields will be discussed. Based on the gaps in knowledge present within the literature and the likelihood of increased exposure at altitude as uncovered in Chapter 1, the research question for this thesis will be introduced.

2.1 Introduction

A review of the English language literature was undertaken to identify relevant studies. All electronic searches were made through PubMed, Medline and Cochrane databases.

To identify the effect of UV and blue light on the eye, searches were conducted using the following key words: 'Ultraviolet', 'UV', 'blue light effect', 'blue light hazard' with 'ocular' and 'eye'. Due to the large number of publications in this field, prioritisation was given to more recent publications and to review papers. To find publications measuring cockpit light levels, the following keywords were used: 'Ultraviolet', 'UV', 'blue light', 'blue light hazard' with 'cockpit', 'pilot' and 'airline'.

In order to establish literature on optical transmission properties of cockpit windshields, electronic searches were made through PubMed, Medline and Google Scholar. Additional electronic searches were conducted through the International Civil Aviation Organisation, Federal Aviation Administration, Civil Aviation Authority and Google using keywords: 'optical properties', 'optical transmission' with 'cockpit', 'windshield' and 'windscreen'. Further windshield specification information was sought through relevant CAA departments, aircraft manufacturers and aircraft windshield manufacturers.

To identify the prevalence of ocular and non-ocular UV related pathology in airline pilots, the following keywords were used: 'cataract', 'macular degeneration', ‘maculopathy’, ‘keratopathy’, ‘pterygium’, ‘melanoma’, ‘skin damage’, ‘lupus erythematosus’, ‘infectious disease’, ‘vaccination response’ with ‘pilots’ and ‘aircrew’.

To determine studies addressing the use of sunglasses in airline pilots, keywords used were: ‘sunglasses’, ‘eye protection’, ‘UV protection’ with ‘pilots’ and ‘aircrew’. Additional searches were made through Google and Google Scholar to identify relevant journal articles. Searches were also made through aviation medicine books, the International Civil Aviation Organisation, Federal Aviation Administration and the Civil Aviation Authority.

Relevant papers from conferences and any relevant papers referenced from the original search were included. The final electronic search was conducted on 21 July 2014. The paper by Chorley et al (2011) reviews the literature surrounding occupational ocular exposure to non-ionising radiation in professional civilian pilots. This included the majority of the studies described in this chapter.

2.2 Aircraft windshield and visor transmittance

One study was identified regarding the optical transmittance of cockpit windshields. Nakagawara et al (2007) measured the optical transmittance properties of eight windshields used in a wide range of aircraft types including Boeing and Airbus. It is not stated whether these were front or side windshields. All measurements were conducted at ground level. The authors attempted to cut a sample from one of the available glass composite windshields, however crazing of the surface made transmittance measurements impossible.

Three radiometers, sensitive to different regions of the spectrum, were used to measure the transmittance of the windshields for radiation in the wavelength range 270 to 780nm in a laboratory setting. Baseline readings without the windshield in place were taken between each measurement. The authors measured two windscreens under laboratory and field conditions for validation purposes.
Six windshields (from large commercial aircraft) were laminated glass with the remaining two being of single-layer polycarbonate material (from smaller general aviation aircraft). The results showed that transmittance was less than 1% through both glass and plastic windshields from 280 to 320nm (UVB). Transmittance varied between 0.41% and 53.5% from 320 to 380nm (UVA) with the plastic material

showing superior UV blocking. For visible light between 400-600nm, the average transmittance was found to be over 80%.

Although the UV wavelength ranges over which transmittance values were quoted differed from the normal ranges used (section 1.2), the study showed that a high percentage of UVA radiation was transmitted through some cockpit windshields. It remains uncertain if the particular conditions at altitude, such as temperature, internal and external air pressure and use of windshield heating elements, would affect transmission. The effect to pilot occupational exposure remains unknown.

2.3 In-flight measurements

Three studies were identified regarding non-ionising radiation levels within the cockpit during flight. Diffey and Roscoe (1990) measured ultraviolet radiation exposure during flight using a ‘polysulphone film’ badge worn by pilots on the epaulette nearest to the side window. Recordings were taken from the captain and first officer on 12 flights including long and short haul on a wide variety of routes worldwide. The total exposure during flight was then measured from the badge although no details of this process were provided. Further measurements were taken with separate badges at ground level ‘around noon’ from an unshaded horizontal surface in five locations worldwide.

The sensitivity of the film was ‘*confined principally to wavelengths less than 320nm’*. No detail was given regarding the accuracy of measurement of the films, the range over which the films were sensitive or the protocol used to activate and deactivate the badges. For calibration purposes, UV levels were also measured by the authors on one flight using a radiometer with a sensor with ‘*similar spectral sensitivity*’ to the badges although these data were not given.

The results showed that all badges worn during flight had minimal exposure to UV radiation and were significantly less than readings taken outside at ground level. Although no statistical analysis was carried out, values were small and projected annual doses fell within recommended annual exposure for indoor workers.

The second study by Roscoe and Diffey (1994) was a preliminary study of levels of blue light within the cockpit. Measurements were taken using a radiometer sensitive to 370-520nm during a one sector flight on a Boeing 767 from London to Spain. The authors state that 50-60% of blue light was transmitted through an Airbus A320 windshield although this differed from the aircraft type used in their study.

A series of readings were taken during climb, cruise and descent with the sensor in various directions. Wide variances in readings were found depending on the direction of the sensor but little effect was found with altitude. Results were within recommended ‘threshold limit values’ defined by the American Conference of Governmental Industrial Hygienists. However, these limits are based primarily upon the threshold irradiance levels to produce acute photokeratitis (World Health Organisation, 1993). No statistical analysis was carried out and it is not known if the results were clinically significant. The authors comment that ocular exposure in flight may be higher due to a slightly nose up aircraft attitude during cruise compared to a marginally stooped human posture on the ground.

Recommendations for sunglasses with less than 10% transmittance of blue light were made. It was not clear how this was derived based upon the data. The authors acknowledge that this was a preliminary study, however no further published work was found.

The third publication by Chorley et al (2014) describes the equipment used in this study and the considerations required for in-flight measurements. This information is also described in chapter 5. Some in-flight data is also presented in this paper which is presented, together with all other in-flight data in chapter 6.

2.4 Ocular effects of chronic UV/blue light exposure

The areas of the body at most risk of excessive exposure to UV are the eyes and the skin (World Health Organisation, 2006). Less than 1% of UV radiation below 340nm reaches the retina; the remainder is absorbed by the cornea and lens. This means that most UV is absorbed by the anterior structures of the eye, the cornea and lens, which are therefore most at risk of damage. There is evidence to suggest that long term exposure is sufficient to disrupt its structure (section 2.5). Doses for UV and blue light are likely to be increased where there is good visibility with less atmospheric pollutants, where there is a lower solar elevation angle closer to the line of sight and where there may be surface reflections present such as from snow (Hietanen, 1991).

It is known that intense exposure to UV can disturb the cornea, which absorbs all UV below 300nm and 40% of UV at 320nm (World Health Organisation, 1993). This can cause an acutely painful inflammation of the cornea, known as photokeratitis. This has not been reported within the cockpit as the UV levels from a broadband source such as the sun are not sufficiently intense to invoke this response. It generally occurs following insufficient eye protection where sunlight is reflected from snow or during electric arc welding (Sliney, 2002). A large body of evidence supports the proposition that long term exposure to UV is a risk factor for cataract (Cruikshanks et al, 1992; Delcourt et al, 2000; McCarty et al, 2000). UV induced cataracts are likely to arise through oxidative stress causing increase in reactive oxygen species (chemically reactive molecules which can, in turn, cause damage to the lens DNA and cross-linking of proteins) (Brown and Bron, 1996). It is recognised that cataract development is multi-factorial with age being a strong risk factor and with other reported risk factors including cigarette smoking, diabetes, nutrition, obesity, genetic factors, steroids and alcohol (Aspell et al, 2005). There is a higher risk of cortical cataract with UVB exposure consistent through different study designs, different populations and varying levels of other known risk factors (McCarty and Taylor, 2002).

Radiation incident to the eye at a peripheral angle is focused by the cornea on the nasal limbus and nasal lens cortex. At the limbus, the peak was found at an angle around 120° from the normal plane causing an 18.3 increase in UVA (Kwok et al, 2003). For the lens, a peak intensity of 8.6 times increase at an angle of 84° was found (Kwok et al 2004). This effect, known as the Peripheral Light Focusing (PLF) effect offers explanation as to the higher prevalence of early cortical cataracts in the lower nasal quadrant (Wolffsohn, 2013). Although there is only weak evidence for any association of UV exposure with other ocular surface conditions (World Health Organisation, 1993), the PLF effect may offer further explanation as to the nasal location of pterygium (Coroneo, 2011).

A multi-centre study by Brilliant et al (1983) assessed the presence of cataract in 30,565 life-long residents of Nepal and found a positive correlation ($r=0.563$, $p<0.001$) between cataract and increased sunlight exposure. Surprisingly, there was a negative correlation of similar magnitude between altitude and cataract prevalence, which the authors attribute to tall neighbouring mountains blocking the sun. The authors did not consider other potentially confounding factors, such as diet.

Increasing evidence (Young, 1988; Taylor et al; 1992, Algvere et al; 2006) supports an association between solar radiation exposure and the risk of age-related macular degeneration (AMD). This condition involves degeneration of the photoreceptors in the macula area of the retina (Millidot, 1990) and is the most common cause of irreversible visual loss in the developed world in individuals over 50 years of age (Kanski, 2007) and which is likely to become more prevalent with an ageing population. Taylor et al (1992) found that, in a population of watermen, those with advanced dry AMD had significantly higher exposure to predicted blue or visible light but no difference with regard to UVA or UVB exposure. Deep blue light has been described as being 50-80 times more efficient at causing photoreceptor damage than green light (Voke, 1999). This 'blue light hazard' has an excitation peak around 440nm (due to the photobiological action spectrum). The degree of retinal exposure is affected by eye movements, pupil size, transparency of ocular media and aversion responses (Parisi et al, 2004).

Although some of the evidence is limited by the use of animal models (section 2.5), there is persuasive evidence that long term exposure to high levels of solar radiation is a factor in photoreceptor damage and a plausible mechanism for the damage has been identified (Ham et al, 1976; Pang et al, 1998; West and Schein, 2005).

There is increased risk of late AMD following cataract removal and lens implant (Algvere et al, 2006) as the crystalline lens absorbs an increasing proportion of shorter wavelength visible light during cataract development. UV and blue light hazard blocking filters have been shown in animal models to significantly protect against retinal damage. Intraocular lens implants with short wavelength filtering properties are being used increasingly. Additionally, it has been proposed that a sensitivity to glare and poor tanning ability increase AMD risk (Darzins et al, 1997). Outdoor leisure time has been significantly associated with an increased risk of early AMD in later years (Cruikshanks et al, 2001). The risk of eye conditions such as cataracts, pterygium and macular degeneration may be reduced by the reduction in human exposure to UV (Young, 1994).

The presence of cataracts have the potential to cause disability glare through increased intra-ocular scatter and reduced retinal image contrast (Brown, 1993). Retinal macula pigment has not been found to decrease significantly with age (Cuilla and Hammond, 2004) but is reduced in those with macular degeneration. Discomfort and disability glare have been shown to be increased with reduced macula pigment (Stringham et al, 2011). Additionally pupil size, which generally decreases with age, is associated with higher level of discomfort glare (Stringham et al, 2011). These factors mean that older pilots are more likely to be affected by glare.

2.5 Biochemical mechanism for retinal damage

There is a large amount of published research into the effect of UV and visible light on the retina and there are three independent mechanisms by which retinal damage can occur. These are known as photomechanical, photothermal and photochemical processes.

Photomechanical damage can occur following high irradiances of short duration which in turn can generate shock waves causing permanent retinal tissue damage. Other types of damage may occur when photon energy is absorbed by the retinal tissue. For this to occur, the photon energy must be equivalent to the energy difference between a retinal molecule's energy state and a higher energy level excitation state. In the photothermal process, collision of molecules as energy is dissipated causes an increase in temperature which, if sufficiently great, can cause irreversible tissue damage. Photothermal damage generally occurs after short (less than 1 second) exposures (Youssef et al, 2011).

Photochemical damage is associated with longer duration exposure times and exposure to shorter wavelength light. It is reported to be the most common mechanism involved in retinal light damage (Youssef et al, 2011). Photons interact with chromophore molecules in the retina and retinal pigment epithelium (RPE) and cause electrons to be changed from a ground to an excited state. Where there are more photons of energy capable of causing this change, a greater probability exists that this process occurs. Thus, photochemical reactions are dose dependent (Mellerio, 1994). Electrons may return to their ground state, releasing the energy previously absorbed. However, other interactions involve the generation of free radicals. These are formed where a bond is split in another molecule causing the production of an unstable singlet oxygen species. These free radicals can cause permanent damage to other molecule types including neurosensory retina and RPE (Wu et al, 2006).

There are two classes of photochemical damage described in the literature. Both types of photochemical damage have been extensively studied in animals with various thresholds for retinal damage caused by factors such as diurnal or nocturnal species, axial length (Ham & Mueller, 1989) or animal rearing environment (Organisciak & Vaughan, 2010). The data in humans is more limited and care must be taken in extrapolating findings in animal studies to humans.

Type I photochemical retinal damage from chronic exposure to bright light (Noell et al, 1966; Mellerio, 1994) has been described and it has been suggested that prolonged bleaching of rhodopsin causes photoreceptor damage (Organisciak and Vaughan 2010). This damage is linked to light interaction with rhodopsin within the retinal photoreceptors. Its action spectrum corresponds well with the spectrum of the visual pigments (Noell et al, 1966) and it is likely to involve large areas of the retina.

ICNIRP state that the exposure conditions in animal experiments to produce Type I damage were extreme and would exceed those levels experienced by humans to a broadband source. Therefore no exposure limits are recommended by ICNIRP for type I (Noell) damage.

Type II damage was described initially by Ham et al (1976) and is characterised by shorter exposure times to higher irradiances with an action spectrum which peaked towards short wavelength visible light. Typically, this damage results in a smaller area of retinal damage as the incident radiation has had to be collimated to produce retinal damage in a laboratory setting (Youssef et al, 2011). Type II retinal damage shows clinical signs that bear close resemblance to the early stages of AMD (Ham and Mueller, 1989).

It is thought that blue light damage may be the result of a number of processes, (Ham et al, 1976) and this is supported by subsequent literature (Mellerio, 1994), however it does appear to involve the production of free radicals, particularly oxygen. Melanin, which is found in the RPE, protects its cells from oxidative damage. It has been suggested that ageing and years of daily light doses can cause the anti-oxidant properties of melanin to decrease which in turn increases the risk of retinal damage.

The macular pigments lutein, zeaxanthin and meso-zeaxanthin are reported to offer retinal protection through absorption of higher energy blue light (Youssef et al, 2011). The absorption spectrum peaks at 460nm and it is estimated that approximately 40% of visible blue light is absorbed by these macular pigments (Loane et al, 2008). Individuals with higher levels of macular pigment are reported to be at lower risk of AMD (Kaya et al, 2012).

An elevation in body temperature reduces the repairing capacity and subsequently reduces the threshold for photochemical damage (Mellerio, 1994). Susceptibility to photochemical damage may vary depending on the point on the circadian cycle at which exposure is received. In animal experiments, Duncan and O'Steen (1985) showed that greatest retinal damage occurred with exposures at the end of dark and beginning of the light cycle.

2.6 Effects of cumulative dose

Photochemical damage is reported to be both dose dependent and cumulative in nature (Youssef et al, 2011; ICNIRP, 2013). Albert et al (2010) showed progressive stages of retinal degeneration and choroidal neovascularisation in albino rats following long-term cyclic light exposure of up to 6 months.

It has been shown that repeated exposures below levels at which retinal damage would be expected to occur during a single dose, can still cause retinal damage. Noell et al (1966) showed that while a 5 minute exposure to light caused no significant damage to retinae in rats, four separate 5 minute exposures separated by a one hour recovery caused significant retinal damage. Additionally Greiss and Blankenstein (1981) suggested a cumulative dose effect of retinal exposures for up to 4 days based on approximately 17 minute exposures of blue light to rhesus monkeys. The authors suggest a formula to provide an estimation of a revised exposure limit in cases of repeat exposure within four days. However, the cumulative effect of repeated doses are unlikely to be additive for a number of reasons including the effect of aversion responses and the potential of retinal repair between exposures (Mellerio, 1994). It is reported that where incident radiation destroys molecules faster than they can be repaired, the net effect will be an increase in damage. Where exposure times are long and irradiances low, the repair process may balance the damage mechanisms, known as photostatis (Penn and

Williams, 1986). The presence of raised levels of retinal lipofuscin may predispose the retina to photochemical damage (Loane et al, 2008).

Numerous publications have explored the relationship between long term light exposure and changes seen to the central retina including pigmentary changes to the RPE, drusen, macular oedema and AMD (Ham and Mueller, 1989). The conclusion drawn is that prolonged light exposure affects the phagocytic ability of the RPE with accumulation of cellular debris around Bruch's membrane (Ham and Mueller, 1989).

Due to difficulties in research into lifetime light exposure and the risk of retinal damage and AMD, studies have used proxies including sun avoidance behaviour, iris colour, skin tone, facial wrinkles and history of severe sunburn or skin cancers to estimate overall solar exposure. Results for sunlight and AMD are inconclusive even in large scale studies such as the Beaver Dam Eye study (which found a higher incidence of RPE changes in blue eyed individuals) (Cruikshanks et al, 1993) and Blue Mountains Eye Study (which found no association in 5 year longitudinal data) (Wang et al, 2003). Additionally, the applicability of the use of proxies would be questionable for a pilot population who occupationally are receiving solar radiation filtered by the windshield.

2.7 Prevalence of UV/blue light exposure related pathology in pilots

Four studies were found investigating the presence of cataracts in airline pilots. No studies assessing the incidence of other UV related conditions including AMD in pilots were found.

Nicholas et al (2001) investigated self-reported disease rates among 6,609 active and retired American and Canadian airline pilots from two airlines through questionnaires. Data collected included age, gender, race, start and end years for commercial flying, lifestyle questions, presence of cataract, cancer and non-cancer disease endpoints. The authors utilised an estimated standardised incidence ratio, using the length of time as a commercial pilot, to compare their data with available data from the general United States population. It was acknowledged that this could induce error as self-reported data in the pilot group was compared to record-based data in the control group. Additionally, the study group would have had to be free from disease at their initial medical and may not be representative of the general population.

A significantly higher incidence of cataracts in the pilot population was found. It was unclear how the authors or subjects defined cataract or how the questionnaire was worded in order to collect these data. The type or grade of cataract present was also not known. The authors found a significantly higher rate of motor neuron disease, which they felt was due to inaccuracy of pilot reporting. This may raise some doubt over the accuracy of the other data.

Rebok et al (2007) studied a cohort of 3,019 male pilots (age 45-54 years) retrospectively over a 10-year period. Data were collected through the United States aviation medical records system. The research aim was to identify age-related visual problems. The study contained no control group and therefore no comparison could be made to the general population. The authors aimed to assess the risk of visual problems with flight experience and age through parametric modelling.

Data were collected on a wide range of ocular pathologies and grouped into broad categories. The most prevalent visual pathology was 'corneal problems'. No further details were given and it is unknown if any were attributable to UV exposure. Cataract was the third most common visual disorder. No details of type or grade of cataract were given. For analysis, all data were combined to give a relative risk of '*visual problems*' with flight experience. With regard to the presence of UV related pathology, it can only be concluded that cataracts were present in some pilots.

Kagami et al (2009) conducted a retrospective cohort study over a 12-month period to determine the prevalence of cataract in 3,780 Japanese airline pilots. Medical records were examined by one of the authors for the presence of cataract. Those cases detected had further data collected including age at diagnosis and aeromedical decision outcome. The cataract type was classified by the authors based upon the documented appearance on record. It is not clear if this diagnosis differed from that of the original examiner and no inter-observer reliability measures were taken. Cataracts were documented as congenital or secondary/age-related.

The authors compared their results to a Japanese population study and concluded that the prevalence of cataracts in the pilot population was '*significantly lower'* than the general population. The most common age-related cataract detected was cortical followed by nuclear. No raw data were given and no statistical analysis was conducted. The authors question whether the pilot population is healthier than the general population but conclude that early cortical cataract at aeromedical examination may be missed as routine dilated eye examination was not carried out. It is not known how these data compare to pilots of mixed racial origin as in the UK.

Rafnsson et al (2005) conducted a population based case-control study using 71 pilots and 374 controls. Cataracts were quantified and graded according to World Health Organisation classification and all participants completed a lifestyle questionnaire. Cumulative cosmic radiation doses were estimated for the pilot group. Cosmic radiation consists of ionising sub-atomic (mainly proton and alpha) particles that do not form part of the electromagnetic spectrum. A higher prevalence of nuclear cataracts was found within the pilot group, which was attributed to cosmic radiation. The two groups were not age-matched and the study group had a higher prevalence of smoking, a risk factor for nuclear cataract (Kelly et al, 2005). No acknowledgement was made in the paper of the potential effect of UV radiation to the pilot population. Criticism was received (Facius, 2006) as the authors' estimated cosmic radiation doses were argued to be comparable with normal background levels.

Hammer et al (2009) reviewed the evidence of cancers in aircrew. An approximately two fold increased risk of melanoma was found in cohort studies. A weak link was found to cosmic radiation but an established link was present between UV exposure and melanoma and non-melanoma skin cancers. A recently published meta-analysis of melanoma in airline pilots and cabin crew (Sanlorenzo, 2014) found a standardised incidence ratio for melanoma of 2.22 ($p=0.001$) for pilots. It was suggested that this increased incidence in pilots was due to occupational exposure. Dos Santos Silva et al (2013) assessed the incidence of cancers in 7,878 flight crew and 1,822 air traffic controllers based on aviation medical records and the results of postal questionnaires assessing lifestyle and demographic variables. Skin melanoma showed a higher incidence in both occupations and showed increasing incidence rates with flying hours (p-trend = 0.02). Further analysis between the two occupations showed no significant difference in melanoma incidence rates. Skin type and sunbathing habits were reported as the strongest risk predictors.

2.8 Use of eye protection by professional pilots

There was one publication on this topic (Chorley et al, 2013) which was written following the results of the interviews described in chapter 4. There were no other studies investigating pilot use of sunglasses were identified in peer-reviewed journals. A number of articles published in aviation magazines and electronically were identified. These articles (Dully, 1990; Federal Aviation Administration, no date; Spencer 2003a; Spencer, 2003b) aim to offer guidance to a pilot or medical examiner and are summarised in Table 2-a together with the CAA guidance material (Civil Aviation Authority, 2008).

Source	**CAA guidance material, 2008**	**Dully,1990**	**FAA guidance, no date**	**Spencer, 2003**
Lens material	Not stated	Glass or polycarbonate	CR39 plastic or polycarbonate	CR39 plastic, glass or polycarbonate
Tint colour	Grey or brown Graduated tint may be useful	One that allows short wavelength blue block, no colour distortion, contrast enhancing without misrepresentation	UV blocking grey, gray-green or brown No appreciable colour distortion	Grey, green or brown Graduated tint may be useful
Tint absorption	Up to 80%	Up to 75%	70-85%	80-85%
Spectacle frame	Well fitting		Sturdy, comfortable, compatible with headset	Comfortable fit
Photochromic lenses	Discouraged	Inappropriate	Discouraged	Try before buying
Polarising lenses	Discouraged	Inappropriate	Inappropriate	Inappropriate
Other recommendations	Graduated tint Lens large enough to allow sufficient protection from oblique sunlight	Optimum tint will vary between individuals More than 1 tint may be needed during flight. 20% absorption yellow tint in low visibility	Small lenses not practical	Large lens Tint should not completely block part of the visible spectrum

Table 2-a Summary of published material offering advice to pilots selecting sunglasses

Within the cockpit, the effectiveness of photochromic lenses, which react to UV radiation, may be reduced due to absorption properties of the windshield. As the lenses take longer to lighten, they may not react rapidly enough when descending through cloud. As polarising lenses allow through light’s transverse wave motion in only one direction (Millidot, 1990), they can cause distortion patterns from some laminated cockpit windshields, render certain liquid crystal display (LCD) instruments invisible, alter cloud appearance and reduce ground reflections useful for pilots. All authors recommend against the use of polarised lenses by aircrew and warn against the potential drawbacks of photochromic lenses.

Rosenthal et al (1988) assessed the UV protection qualities of 32 pairs of 'discount price' sunglasses (16 glass and 16 plastic) purchased from drug stores in the United States. Measurements were taken with two separate UV detectors and a radiometer. A manikin head was used with a detector placed at the eye position behind a 4mm and 10mm aperture. Readings were taken in natural daylight in a horizontal plane with and without sunglasses. Measurements were taken with the sunglasses fitted against the manikin forehead and repeated '*approximately 6mm*' away.

Results showed that UV exposure ranged from 0.8 to 14.1% with no difference between glass and plastic lenses. At the 6mm position, the exposure ranged from 3.7 to 44.8%. No statistical analysis was presented, however the study did highlight the importance of frame fitting on sunglass selection. Increased exposure to UV (295-350nm) was also measured by Rosenthal et al (1986) where prescription spectacles were moved to 6mm away from a manikin forehead.

2.9 Research underpinning pilot marketed sunglasses

Due to the lack of research evidence as to the levels of irradiance received during flight or the prevalence of non-ionizing radiation related ocular pathology in the pilot population, the need for a pilot to use sunglass filters with higher attenuating properties than the current standards such as ISO, cannot be substantiated. Whilst it would seem logical that sunglasses should be lightweight, offer a reasonably low luminous transmittance and offer good protection from peripheral radiation, only this researcher has produced a peer-reviewed scientific publication addressing common issues with sunlight that pilots encounter during flight.

2.10 Discussion

Decreasing (shorter) wavelength radiation has progressively more energy per photon. Certain wavebands are associated with a higher risk of cellular damage through photochemical reactions. The effect of solar exposure on ocular health has been extensively researched and there is strong evidence that UV radiation exposure is a risk factor for cortical cataract formation (Cruikshanks et al, 1992; McCarty and Taylor, 2002; World Health Organisation, 1993). The presence of cataract, even in early stages, can affect visual performance particularly in low light conditions. It can reduce visual acuity as measured by a standard visual acuity chart, it can reduce the ability to see objects that have low contrast against their background (Bennett, 2007) and glare may become troublesome because the cataract causes intraocular light scatter.

There is no strong evidence in the literature indicating an increased prevalence of cataracts in airline pilots. In particular, no study questioned pilots on their use of optical correction and sunglasses. There is increasing evidence of retinal damage with prolonged UV or blue light exposure (Algvere et al, 2006; Cruikshanks et al, 2001; Young, 1998), however there is no evidence available in the literature of the prevalence of AMD in civilian aircrew.

Nakagawara et al (2007) demonstrated that at ground level, many airline cockpit windshields transmit a higher percentage of light of wavelength over 320nm (UVA) but effectively block UVB. This does offer one explanation of the finding by Diffey and Roscoe (1990) that pilots were exposed to insignificant levels of UV. The detectors used in the study were sensitive to wavelengths below 320nm, however these frequencies would have been blocked by the windshield assuming it to be a similar design to that measured by Nakagawara et al (2007). Roscoe and Diffey's 1994 study was not followed up yet requires further data to address the variation of blue light in flight under differing conditions.

With a projected increase in UV in excess of 170% at cruise altitude compared to sea level, the transmission properties of airline windshields at altitude are likely to be important but remain uncertain. Whilst it seems likely that UVB radiation remains negligible in the cockpit at altitude, significant levels of UVA and short wavelength light around the blue light hazard (440nm) may be present. If this hypothesis is confirmed experimentally, any occupational risk to ocular health will be best assessed using ICNIRP exposure limit guidelines.

Many pilots are required to wear corrective spectacles in order to meet the regulatory vision standards for flying. A degree of UV protection is offered from untinted prescription glasses. Where pilots choose to wear prescription sunglasses in situations of bright light and glare, further enhanced eye protection should be afforded. Additionally, the use of aircraft sunshields and protective headwear may further control the level of short wavelength light entering the eye. Pilots flying in daylight hours are exposed to solar radiation often for periods of many hours during a flight. Reflectance from cloud tops is likely to increase incident solar radiation. Pilots are protected by the aircraft windshield, which ideally should absorb most ultraviolet radiation but there is very little data to show they reliably do so. There is no standard for the optical transmittance properties of aircraft windshields.

2.11 Research question

Based on the evidence of increased irradiance at altitude and the gaps in knowledge discovered regarding both pilot ocular pathology and measured exposure, a research question was generated. This is: "Is there a risk to the ocular health of airline pilots from exposure to UV and short wavelength blue light during flight?"

It is recognised that the research question would be influenced by a number of factors. Therefore a series of research aims were established which together would address the research question. These aims are as follows:

- Establish the extent to which sunlight may be an issue to commercial pilots and to explore the range and frequency of eye protection used.
- Measure light spectra and irradiance during flight within the cockpit with particular reference to irradiance at the pilot's eyes.
- Assess the effectiveness of those sunglasses used by pilots during flight
- Produce the data to inform evidence-based guidelines to pilots on sunglass and prescription lens selection.

3. Chapter 3 Research Design

CHAPTER OVERVIEW

This chapter introduces the ontological and epistemological stance for this research and introduces a series of objectives which together aim to address the research question. These objectives translate into three main project research phases. The results of one phase may inform the methods of a subsequent phase or contribute to answering the research question. A summary of how these phases and project components interlink is introduced together with the format for subsequent chapters.

3.1 Philosophical framework

Scientific research involves the systematic study of the phenomena of interest by detailed observation using the senses and often aided with the use of technical instruments (Bowling, 2009). Accurate measurement is essential and should be taken under controlled conditions to minimise any contamination of results by external factors. These may include experimenter bias or inaccuracies in equipment. Research should strive to obtain freedom from bias and demonstrate rigour in that it shows validity and is repeatable. Validity can be demonstrated by ensuring that the methods and instruments used measure what is intended.

The development of the research design has been formulated by deductive reasoning as the initial pilot enquiries described in section 1.1 led to a hypothesis and research question which would be tested by data gathering and analysis. The ontological and epistemological stance of the researcher is a positivist one in that it is felt that there is a single objective reality (Bowling, 2009) and that the areas of interest in order to answer the research are measurable and can be tested using data. The results should therefore be undistorted by the researcher as objective systems of measurement were used.

3.2 Research objectives

There were a number of important factors which would influence the area of research. A study designed to address only one aspect would not be able to satisfactorily answer the research question. Three sub-part questions were formulated which it was felt together would comprehensively address the research question: “Is there a risk to the ocular health of airline pilots from exposure to UV and short wavelength blue light during flight?” These sub-part questions were:

1) What are the eye protection practices employed by pilots during flight and how commonly are they used?
2) What typical ocular irradiance is received during flight?
3) How effective are the typical sunglasses used in reducing the pilot’s occupational ocular irradiance?

From these, a series of related yet independent studies were designed using different research methods. The research has been categorised into three distinct phases. Phase 1 addressed sub-part question 1, the aim of phase 2 was to answer question 2 while phase 3 addressed question 3. The data required was predominantly quantitative in nature.

3.3 Structure of research

A diagrammatic summary is provided on the next page which details the components of each research phase. The summary also demonstrates the proposed outcomes from each phase and how this may assist in answering the research question or informing the methods of another component of the research. The summary also shows the methods used in the research and the numbers of participants, flights or aircraft involved during the data collection.

In order to gain insight into the solar protection practices of professional pilots operationally, some form of interaction with the pilots themselves was required. Phase 1 commenced with a series of semi-structured interviews exploring the issues for the pilot of sunlight in flight, the use of sunglasses and of other eye protection habits. The results of these interviews informed the development of a questionnaire completed by a large number of professional pilots. In addition to sunglass use, the questionnaire also investigated the use of other eye protection strategies, the pilots’ flying background, the type of sunglasses worn and issues with their use, the prevalence of ocular non-ionising related pathology and pilot concerns regarding occupational exposure and eye health. An audit of CAA medical records was also undertaken to determine the number of UK professional pilots, the prevalence of a spectacle requirement and the prevalence of ocular non-ionising related pathology reported or found at medical examination. These studies comprise phase 1 which is described in chapter 4.

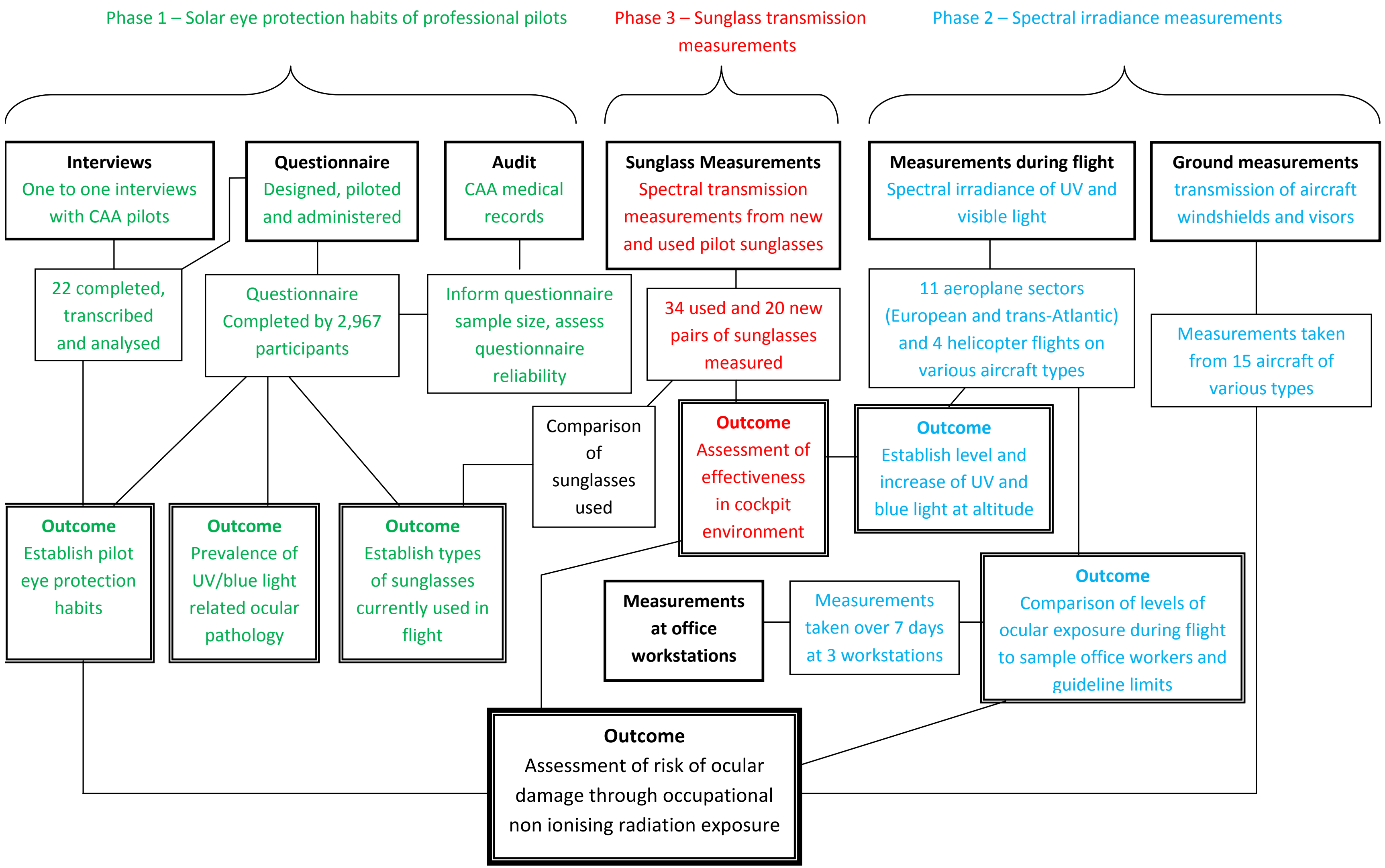

Figure 3-a Diagrammatic summary of research including methods used, size of sample and proposed outcomes.

For phase 2, an observational study was not valid to measure spectral irradiance levels as the human eye is not able to assess the spectral components of a broadband source, is not sensitive to UV radiation and cannot reliably quantify the intensity of radiation. Therefore specialised equipment was required in order to measure irradiance levels across a spectrum. The equipment used was a spectrometer and is detailed in chapter 5. Irradiance measurements were captured throughout a number of commercial aeroplane and helicopter flights in order to ascertain potential pilot ocular exposure and are described in chapter 6. In order to offer some comparison of ocular exposure, a series of spectral irradiance measurements in an office environment were undertaken. This forms chapter 7 whilst chapter 8 describes the results of a series of ground transmittance measurements captured from various aircraft windshields, visors and blinds in order to assess likely ocular exposure in a wider range of aircraft.

Phase 3 consists of a series of transmittance measurements through sunglass filters. These are measurements from both used pilot sunglasses and new sunglasses typically worn by pilots. Using the knowledge gained in chapter 6, the filtering effectiveness of the sunglasses in flight can be ascertained. Chapter 9 describes phase 3 of the research. An appraisal of research methods is described within each relevant chapter.

3.4 Interpretation of results

Although this research contains mixed methods, it should be considered as a series of smaller studies with the results of one part informing other parts or adding direct value to addressing the research question.

For example, the results of the interviews were used to inform the development of the questionnaire. The results of the questionnaire informed the selection of sunglasses for phase 3 as well as directly providing data to address the research question. The results of irradiance measurements determined the level of protection that will need to be afforded by sunglasses. The research was not considered to be true mixed methods (Gelling, 2014) and therefore has not been subject to a typical documented means of triangulation (Murphy et al, 2014).

3.5 Ethical considerations

3.5.1 Phase 1

In addition to formal ethical approval (section 3.5.4), approval for approaching select CAA staff for interview was sought and given by both the Chief Medical Officer and Head of Flight Operations at the CAA. The identified study group, who were all professional pilots, were sent research information sheets at the time of invitation (appendix D). If agreeing to participate, the researcher discussed the content of the research information just prior to interview and a written consent form (appendix E) was signed by all participants. Audio recordings of the interviews were saved as an anonymised electronic file and stored on the researcher's password secured computer. Subsequent transcripts were kept in a locked cupboard in the researcher's office. A separate electronic file was kept to track the participants interviewed and the file name to which the recording was saved. Files are to be deleted after ten years (2021).

Participants were free to withdraw from the study at any time without giving a reason. If data had already been collected when a decision was made to withdraw, it would have been deleted. It was recognised that interviews should be conducted in a quiet, mutually convenient neutral venue (Oppenheim, 1992). One of the small conference rooms available at CAA Aviation House was used. It was stressed on the information sheet and at the start of the interview, that other ocular or general medical concerns would not be discussed and that these issues should be raised at either the next routine renewal aviation medical or, if significant injury or illness involving incapacity to function as a member of flightcrew, in writing to the medical department as laid out in the Joint Aviation Requirements (JAR-FCL 3, 2006). These were the European aviation medical standards at the time of data collection.

Pilots are an informed group and, by definition, would have passed an examination in air law during flight training. The CAA's routine work is regulation and enforcement. Pilots breaching medical regulations are normally managed by advice, as typically their transgression is not intentional. Although considered unlikely, a case of willful transgression of a medical regulation by a participant could be prosecuted by the CAA. However, a transgression of medical regulation would not be managed any differently whether the pilot was in or outwith this study.

For the questionnaire, research information was given at the start of the survey. This included some background information regarding the research, assurance that results were only to be used for research purposes, that participation was voluntary and that data would be appropriately managed (appendix F). Participants would be considered to have given implied consent if they, having been presented with the study information, had gone on to complete and submit the questionnaire.

3.5.2 Phase 2

The main ethical consideration for in flight measurements is that of ensuring that flight safety is maintained. Prior to the formal research ethics application, a risk assessment document was drawn up in consultation with spectrometer equipment manufacturer detailing the technical specifications of the equipment, its proposed use in the cockpit and any foreseeable areas in which an effect to aircraft systems could occur (appendix G). This document provides the basis from which airlines, aircraft engineers and flight crew can assess its compliance to fly. On the day of each data collection, the researcher would be prepared to remove equipment or not be permitted on board if there were any safety concerns or overriding operational requirements.

It was important to ensure that the researcher gained airport airside security clearance so as not to impede potential access to aircraft. Additionally, it was recognised that appropriate study approval (appendix H) and equipment information (appendix G) documents should be carried and presented if required, at airport security.

3.5.3 Phase 3

A consideration specific to phase 3 was that the pilot must give consent to loan of their sunglasses for measurement. The researcher should ensure that care is taken of the sunglasses during data collection and that they are returned in no worse condition and in a timely manner.

3.5.4 Research ethics approval

A research proposal covering all three phases of the research was submitted to London South Bank University and the Institute of Optometry Research Ethics

Committees. Letters of approval were received from both Research Ethics Committees and are shown in appendices I and J respectively.

3.6 Summary

A series of objectives have been described which will be addressed in three phases in order to answer the research question. The anticipated research outcomes from each part have been described and contextualised within the overall research. Different methods are employed for each phase.

Chapter 4 will describe the components of phase 1, that of the series of exploratory interviews which inform the questionnaire design, the questionnaire results and the results of the audit of the CAA medical records. Chapter 5 will introduce the spectrometer and illuminance UV recorder equipment and describe their specifications, limitations, calibration and software. Chapter 6 will describe how the equipment was used for measurements during flight and present the results from this part of project phase 2. The remaining components of phase 2, that of office measurements and aircraft ground transmission measurements are described in chapters 7 and 8 respectively. Sunglass transmittance measurements forming phase 3 of the research is described in chapter 9.

4. Chapter 4 Solar Eye Protection Habits of Professional Pilots (Phase 1)

CHAPTER OVERVIEW

This chapter covers the aspects as part of phase 1 of the research. Firstly, a series of semi-structured interviews with experienced pilots to determine the range of sun protection practices will be described. These results assist in informing the development and deployment of an online questionnaire to a large number of professional pilots which forms the main part of this phase. Finally, an audit of CAA medical records will be described to determine the number of current UK professional pilot licence holders, the number with an endorsement for optical correction and the reported prevalence of non-ionising radiation related ocular pathology.

4.1 Introduction and appraisal of methods for phase 1

As the researcher was not involved in commercial flight operations, the logistics of gaining access to the operational cockpit environment across differing flight environments would be challenging. This meant that the ability to conduct an observational study of pilot practices in flight was limited. As the aim was to ascertain the eye protection habits of a large number of professional pilots across varying flight operations, it was felt that a questionnaire would be the most appropriate method to use.

The CAA is the independent specialist regulator to the aviation industry and the researcher is an employee of the CAA. If the industry regulator is seen to be collecting data, participants may not wish to fully disclose practices that may be seen to influence medical certification or career. Even with appropriate reassurance in place, significant bias may still be present and a true picture of pilot practices may not be determined.

To minimise bias and to optimise response rate, it was decided that the questionnaire should be internet based and that data would be anonymous. Therefore, no personal details (such as name, date of birth or CAA reference number) would be collected which could identify the individual respondent. It was recognised that care would be needed to ensure that the questionnaire was targeted at professional pilots and not readily available for completion by other groups.

It was also recognised that careful attention should be paid to the visual appeal of questionnaire and the ease of which it can be answered and returned (Denscombe, 2007). There is some evidence to suggest little difference between responses from web-based and paper format questionnaires (Denscombe, 2006) however it may prove more difficult to apply effective study group targeting through a web-based questionnaire (Denscombe, 2007).

The aim of the questionnaire was to elicit candid responses from a large number of current professional pilots as to the solar eye protection practices and issues encountered with bright sunlight in flight. The questionnaire was to be designed to address the following broad areas:

a) How much are sunglasses used and what are the factors affecting whether sunglasses would be worn?

b) Are there issues encountered with managing bright light in the cockpit and what factors affect these?

c) What other strategies are used in flight and how effective do pilots find these?

d) What are the sunglasses used by pilots and are there common factors that are likely to make sunglasses successful in flight?

e) What is the prevalence of UV related ocular pathology reported and are there eye health concerns within the wider professional pilot population.

There was no previously validated questionnaire to address these questions and the range of eye protection practices was not known. Although a newly designed questionnaire would be required, it would need a solid knowledge base of the range of eye protection habits likely to be encountered across various flight operations.

It was decided that in order to inform the questionnaire, a series of interviews should be conducted using a small number of experts. Expert interviews were described by Meuser and Nagel as a specific form of semi-structured interviews where the interviewees are chosen due to their expertise in a certain field of activity (Flick, 2009). A semi-structured approach applies a mixture of structured and open-ended questions in order to elicit more in-depth and wider ranging responses from participants (Bowling, 2009).

One way in which expert interviews can be successfully used is in exploration and orientation in a new field with the results to be used to prepare the main research instrument in the study (Bogner et al, 2009). These types of interview place less importance on a person and more importance of the collective knowledge of the group on a specific topic. It is recognised that this type of method is narrow in its objectives and may not lend itself to a single method approach (Oppenheim 1992), however this fitted well with the aim of this phase which was exploratory and whose purpose was to inform a larger scale research study. It is also recognised that the interviewer has to have some familiarity of the topic to understand the degree of relevance of responses and be able to ask the right questions in order to probe for further information. The researcher holds a private pilot's licence and therefore has some experience of the operational aviation environment.

It was decided that the study group would be current professional pilots employed by the CAA. CAA Flight Operations Inspectors (FOIs) are experienced commercial and airline pilots who visit, observe and fly with commercial operators to ensure that safety standards are maintained. In addition to having extensive flying experience themselves and flying with other professional pilots, they are also trained to observe other pilots. They would therefore be in a position to comment not only on their own practices, but also on the practices of others.

It was felt that one-to-one interviews were likely to reveal a richer data source than a focus group. Both researcher and pilot would likely be more used to communicating on a one-to-one basis. Focus groups may have been more difficult to manage and to keep on topic where all participants are colleagues within the same department, discussions could easily deviate into day to day work matters. Additionally, the nature of their role at the CAA means that FOIs have limited time spent at CAA premises affecting the feasibility of organising group discussions. Therefore, the research method of focus groups was excluded.

Most FOIs undergo their routine annual revalidation medicals at the CAA AeroMedical Centre. The researcher conducts the eye examinations at these assessments and has built a rapport with many of the FOIs. It was anticipated that this study group should not hold misconceptions regarding the CAA that may be more prevalent within the general airline pilot community.

The interviews would focus on the issues of sunlight on the flight deck and the eye protection habits of participant during flight. Questions were included to explore differences that may be apparent in various aircraft types and within other pilots. Some questions were designed to elicit any health concerns that the participant may have held related to exposure received on the flight deck.

It was recognised that although the researcher was a clinician experienced in eliciting information from patients in a one to one environment, particular skills would be required to ensure questions were unbiased and that the interviewee had sufficient opportunity to describe relevant information within the conversation. Therefore, training and practice interviews with non pilots were conducted prior to data collection (section 4.4).

4.2 Sample size for phase 1

The number of participants eligible for interview was limited by the number of FOIs employed by the CAA. This was 28 (aeroplane and helicopter) at the time of data collection. It was anticipated that, as most FOIs would know the researcher, response rate would be high. However, it was recognised that some individuals were based at regional offices which would make interviews more difficult to arrange. FOIs generally have between one and three aircraft type ratings on their licence and as a group, operated a broad range of aircraft types. It was decided to invite all FOIs to participate in the interviews.

In order to assess an appropriate questionnaire sample size, a current UK professional pilot population figure was sought. An audit of the CAA medical records was carried out described in section 4.13. No personally identifiable data were collected and the output simply gave the total number of current UK commercial licence holders at the time of audit. Additional data was collected to determine the proportion of licence holders who had a spectacle endorsement on their medical and the proportion who had UV or blue light hazard associated ocular pathology. The results of the audit would also enable comparison of the questionnaire cohort to the overall pilot population.

For the questionnaire, efforts were be made to ensure a high response rate. To ensure this, it was recognised that questions need to be relevant, well structured, appropriate and targeted. It was also recognised that the response rate would be strongly influenced by the relevance and the level of interest that the topic has on the participant (Gillham, 2000). Additionally, the length of the questionnaire and the ease with which it can be completed is known to influence response rates (Gillham, 2000). As the intention was to target only professional pilots, it was anticipated that there would be good topic relevance. Designing an online questionnaire allows the use of logic questions which enables further questions to be triggered only when particular responses to previous questions are made. This helps to ensure topic relevance is maintained and that completion time is tailored for the individual dependant on their responses.

In developing the questionnaire, it was recognised that piloting would form an important role to ensure that wording of the questions was clear and unambiguous, that there were no typographical errors and that the order of questions was intuitive to the respondent (Gillham, 2000). It was also recognised that the questionnaire should be designed so that it should appear to a potential respondent to be research, rather than regulatory in origin. Therefore, affiliation with London South Bank University and the Institute of Optometry was made clear on the study information page at the start of the questionnaire.

An on-line questionnaire additionally has the advantages of lower costs to administer and the ability to export results directly into data analysis software packages such as SPSS (Wright, 2005). The use of an online questionnaire does however expose the potential to be completed by individuals outside the inclusion criteria however the significance of this effect has been disputed (Gosling et al, 2004). As no identifiable information was intended to be taken, there would be no means of assessing that a respondent was a professional pilot. Therefore, the importance was recognised of ensuring not only that a large number of the professional pilot population were invited to participate, but also that invitations were not received by anyone who was not a professional pilot. The British Airline Pilots' Association (BALPA) were approached and a research presentation was made to their Health and Safety Committee. From this presentation, BALPA agreed to promote the questionnaire to all its professional pilot members.

4.3 Interview introduction

The aim was to gain an understanding of the habits and practices of professional pilots with regard to sunglass use and eye protection. It was apparent from the literature that this had not been previously investigated. Additionally, researchers had attempted to establish the prevalence of UV related eye pathology in the pilot population without knowledge of the eye protection practices of pilots (Kagami et al, 2009; Nicholas et al, 2001; Rafnsson et al, 2005; Rebok et al, 2007).

Airline transport aircraft have protection in the form of visors in the cockpit (see section 1.5.7) to shield the sun from the pilot's eyes but it is not known to what extent they are used or what limitations they may have. Additionally, there may be other eye protection strategies that are utilised to aid visual performance, visual comfort or give added UV and blue light protection. A bright light source such as the sun may cause an increase in scattered light within the eye which casts a veiling luminance on the retina, reducing contrast and affecting vision. This is known as disability glare (Mainster and Turner, 2012). The use of an eye protection strategy is likely to be initiated if the pilot becomes aware of disability glare. Discomfort glare can result from an overly bright environment and may affect a pilot even when disability glare is controlled. Therefore, eye protection strategies may be initiated due to visual discomfort. It is also feasible that pilot concerns over ocular safety may initiate the use of eye protection strategies for solar protection. The aim of this phase was to establish the extent to which sunlight may be an issue to commercial pilots and to explore the range and frequency of eye protection used.

As detailed in section 4.1, the results from the interviews would inform the design of the subsequent questionnaire.

4.4 Interview method

A series of semi-structured interviews (Bowling, 2009) were conducted on current commercial and airline pilots. Participants were Flight Operations Inspectors (FOIs) employed by the UK CAA. FOIs are professional pilots whose role is to assess and ensure the maintenance of flight safety standards within the industry. They maintain current flying licences and fly routinely as part of their employment. FOIs will fly with a range of pilots from different carriers and they have previous industry experience flying professionally before joining the CAA. Invitations to participate together with information sheets regarding the study were sent to all 28 inspectors employed by the CAA. For those individuals who did not initially respond, follow up contact was made at least twice by email or telephone.

Prior to the first interview, a series of neutrally worded questions addressing the topics of interest were drawn up. The researcher carried out practice interviews with an optometrist, a medic and pilot and a PhD supervisor. Feedback from these three colleagues enabled the researcher to modify the order and wording of questions and to receive feedback on interview style and maintaining neutrality.

Individual interviews were arranged with each study recruit. These were conducted in a private meeting room away from the work station of both participant and researcher. After verbally confirming the details of the study, participants signed a consent form before undergoing a one to one semi-structured interview with the researcher. Interview data were digitally recorded and stored in accordance with the UK Data Protection Act (Information Commissioner's Office, 2010). The length of interview was typically between 20 and 40 minutes. Participants were questioned about their previous flying experience, their experience with sunlight in the cockpit and their coping mechanisms to manage this. Participants were also questioned on practices that had been observed in other pilots and any eye health concerns that they held regarding exposure to light within the cockpit. The participants were asked to bring any sunglasses used in flight to the interview, where the details of the make and model, tint colour and depth were recorded. A sample tint set was available so that the colour and absorption values could be more accurately assessed.

Each recording was assessed as soon as possible following the interview. Quantative responses were received following some of the closed questions. These data which included flight experience, aircraft type flown, whether corrective spectacles were used and the type of sunglasses or other eye protection strategies used in flight, were input into a Microsoft Excel spreadsheet. The remaining data were transcribed and was subsequently re-checked by the researcher for accuracy and correct contextual interpretation. These transcribed data were then subjected to inductive coding (Bowling, 2009) and categorised where common themes and responses between participants were found. This was carried out by cutting sentences or paragraphs from printed transcripts and separating into themes (Bowling, 2009) whilst maintaining participant reference number. Once completed, these themes were re-examined to determine whether appropriate coding had been used, whether further categorisation into sub-categories were required, if similarly coded categories could be combined or if coding was required in more than one theme (Kvale, 1996). This latter scenario did not occur during analysis and all coded data was mutually exclusive. Once revised coding had been undertaken, each theme was subject to further frequency analysis with most recurrent responses scoring highest. Further detail of coding and categories used is given in appendix K.

The data was mainly quantitative in its nature in that it consisted of statements of fact regarding the FOI's flight experience, solar protection habits or involved the recounting of particular experiences in flight. There was no exploration within the interview as to the FOI's personal feeling regarding these topics. Additionally, the participants were experienced professional pilots and the topic was aviation related. It is considered good airmanship to be able to communicate factual information concisely, so it is perhaps unsurprising that responses from these participants would tend to be in the same manner. Although FOIs expressed personal views, these were generally in areas such as the effectiveness of standard aircraft sun protection systems, sunglass preferences or issues with sunglass use. It was therefore considered appropriate that the data were subject to coding and frequency analysis before reporting. In the development of categories for the questionnaire, low scoring responses regarding eye protection were still considered for inclusion as the primary purpose was to explore the full range of eye protection in use by pilots

4.5 Interview results

Twenty two of the 28 (79%) flight operation inspectors participated in the study. Of the six who did not participate, 3 were based at regional offices around the UK and were unable to participate due to difficulties of geographical separation, 2 failed to respond despite at least 3 contacts and 1 was no longer flying and did not wish to participate. Fifteen participants were fixed wing (aeroplane) pilots and seven were rotary wing (helicopter) pilots. The average length of time over which a commercial or airline transport pilots licence was held was 27.4 years (range 12-43 years). Nine pilots also had additional previous military flying experience. Average flight time logged was 11,300hrs for fixed wing pilots (range 6,700 to 17,000hrs) and 6,400hrs for rotary wing pilots (range 3,000 to 10,000hrs).

There were a total of 31 fixed wing aircraft types flown consisting of five aircraft from the Airbus fleet, five from the Boeing fleet plus eight other jet airline aircraft, six business jet aircraft types and seven turbo prop commercial aircraft types. There were a total of 19 helicopter types flown and one airship type in addition to numerous general aviation instruction and aerobatic aircraft. Most FOIs were currently flying more than one aircraft type. This would be less common in pilots employed by larger airlines with a large fleet of one particular aircraft type.

4.5.1 The visual environment

4.5.1.1 External

Certain flight conditions were reported as being associated with the issues with high levels of sunlight in the cockpit. These were dependent on where and when the aircraft was being operated and included bright sunny days, especially where light was reflected from cloud top, snow, or sea. Flying towards a low sun (sunrise and sunset), particularly in early spring and autumn, was consistently reported to be a discomfort or an irritation. A low sun in the cruise was reported to be easier to manage than a low sun on final phases of flight where the pilot is using visual cues outside the aircraft to make a safe approach to land. A low sun on final approach was reported to cause a loss of visual references, loss of depth perception, a higher stress approach and a harsher flare (where the aircraft is in the last moments of a flight, the airspeed is reduced and correct attitude is set). As well as direct sunlight, FOIs also reported difficulties with sunlight from the side of the aircraft reflecting off the instruments making them less easy to interpret. It was generally acknowledged that this was less of an issue with more modern LCD instrument displays. A bright sun through an atmospheric interference such as haze, where the glare source is increased in size through scatter, was also reported as a difficult flying condition.

Although sunlight was recognised as a cause of visual irritation, discomfort and fatigue, FOIs reported coping mechanisms such as increased use of autopilot, instrument flying, using peripheral airfield visual cues or landing on a runway not into sun. It was not felt that there was a flight safety issue although FOIs felt that it was less of an issue for them with increased experience. Interview 8: "*...the cues aren't as obvious as if you weren't suffering from all that glare. I can't see that it's a flight safety issue, its more common sense and good airmanship to avoid those situations if you can."*

4.5.1.2 Internal

Most aircraft have some form of sun protection fitted as standard for the pilot to reduce the levels of bright sunlight in the cockpit. Newer aircraft types and fits were reported to have a more comprehensive protection offered. Large commercial airline transport aircraft generally have the most comprehensive sun protection systems. Although it was felt that improvements had been made to visors, a number of comments were made that manufacturers could make further improvements. Interview 6:"…*there is still a way to go where they could be improved…it doesn't quite cover the area that you want*." However, there was no consensus as to how this could be achieved. FOIs had concerns if visor were too small and did not offer sufficient coverage or were too large and obscured look out.

Some aircraft types were acknowledged as better at offering sunlight protection due to the smaller size of the windows, the thickness of window frames and the depth of instrument combing. Different business jets were reported to have a wide variation in the level of visor protection offered, with some aircraft having no visors. These aircraft may be operated at higher altitudes than airline transport aircraft resulting in a potential increase in pilot exposure during flight.

Although instrument lighting can be adjusted for optimum viewing under light and dark conditions, it was reported that the range was not sufficient for very bright environments. Where instrument lighting was set toward its maximum level, a greater discrepancy between brightness of different instruments and an increase in time to interpret more complex displays were reported.

4.5.1.3 Additional considerations for helicopter pilots

Study participants revealed that many helicopter types have little or no standard fitted visor protection. However, operating altitudes are lower (often below cloud) and flight duration may be short so that no prolonged single leg flying into sun is likely. Additionally, the helicopter offers more flexibility to position the aircraft away from sun on an approach to land.

Comments were made from helicopter FOIs that bright sunlight may make visual height judgement more difficult transiting from hover into forward flight. Additionally, where precise manoeuvring near the ground is required, the effect of moving from light into shade was recognised as more challenging. Those FOIs operating offshore (e.g. to oil platforms) reported, in direct sunlight, that instruments became difficult to interpret due to reflections from the instrument surface of their high visibility jacket.

Helicopter FOIs felt that the environment in which they operated was less ideal than that of the airline pilot. Interview 14 commenting about visors: *"...they vibrate and fall out of the way so you tend to find a place where they won't move again and just leave them there and use those – that tends to be the modus operandi in the North Sea."*

Interview 16: "Helicopter pilots tend to accept their lot in many ways, the vibration, the noise and discomfort and all the other effects you get, being dazzled and blinded by sunlight is just another one of those things that you put up with!"

4.5.2 Coping strategies used

4.5.2.1 Sunglasses

The proportion of flight time where sunglasses were used varied widely in the pilots interviewed. Many FOIs reported using sunglasses for a minority of the time and only in those conditions where sunlight and subsequent disability or discomfort glare was reported as most apparent (in the cruise, flying towards low sun and landing and take-off towards sun).

A difference was found between those FOIs who require corrective prescription glasses for aviation and those who do not. All FOIs (both fixed wing and rotary) not requiring glasses constantly (n=11) used sunglasses at least sometimes in flight. Of those who required corrective spectacles (n=11), five never used sunglasses.
A number of reasons including hassle and distraction in swapping glasses (particularly in single crew operations) were given as reasons for sunglasses not being used. Interview 13: *"I imagine that if you're like me with varifocals, any pair of sunglasses with varifocals would be quite expensive – that's one issue. I think just the hassle would be the other thing."*

Interview 5: *"I think people like me with a prescription, wear clear specs and those without prescription wear RayBan, or something, so I think having prescription specs is a disability if you like in terms of mitigation of glare. I could get a pair of sunspecs which are varifocals but again they are either on or they're off, there's a distraction element."*

The onset of requirement for glasses was a further factor for discontinuing use of sunglasses. Interview 5: *"I wish I had a solution to my own situation of just wearing* *clear specs all the time 'cos there are many occasions where I wish I had some sort of tinted glasses to wear but I don't have a ready solution. I've either got a pair of prescription specs that I have got to buy which are varifocal that I put on or take off, and for me that's not as workable solution as it should be."*

Comfort was the most consistent factor reported in whether sunglasses were worn amongst the non-spectacle wearers. Sunglasses were reported as uncomfortable over a period of time due to pressure of the sides of the frames on the head, discomfort behind the ear, poor compatibility with the headset or the onset of headaches. However, when questioned, most FOIs had not had their sunglass fitting checked or adjusted. Thin, lightweight, comfortable frames were reported as the main requirements for a pair of sunglasses.

Participants reported that the effect of a sunglass filter made the instruments harder to interpret. Some FOIs reported that subsequent sunglasses purchased had a lighter tint for this reason. It was also reported by two interviewees, that they felt their depth perception was affected with sunglasses and that a degree of separation was experienced to the outside world. These FOIs would tend to use sunglasses less and remove them in critical phases of flight such as approach and landing. Other reasons given for not using sunglasses included that they were forgotten, that the individual was not flying frequently and that glare was more subjectively apparent during other tasks (such as sailing, skiing or driving). Additionally, FOIs who had previously worked overseas in sunny climates, reported using sunglasses more at that time and less now that they were based in the UK.

Sunglasses used by the study participants were assessed and varied between 50-85% absorption (estimated against tint samples of known absorption) and were generally fixed green, brown or grey colour. There were no graduated tints. Two FOIs had polarised lenses and one had photochromatic lenses, neither of which are recommended for pilots by the CAA (Civil Aviation Authority, 2008). These three FOIs all required spectacle correction. Of the FOIs not requiring prescription spectacles, the brand of sunglasses that was used most commonly was RayBans (6/10). Most FOIs had no preference for a specific tint colour; of those that did specify a preference (3/22), no consistent tint colour was reported, indicating that it may be personal preference.

4.5.2.2 Use of standard aircraft protection system

A wide range of sun protection was offered in the form of visors and sun blinds in the various aircraft types flown by the study group. Generally it was felt that newer aircraft designs and fits offered a more comprehensive and flexible sun protection system. The sun screens were often larger and covered more of the window area. Interview 6: "*The technology for blocking it* (sunlight) *out in modern aircraft is very good; older aircraft it's not as good partly because they are old and worn and partly because they have not been thought through as much*".

Additionally, modern instruments such as those using LCD displays were consistently reported to be more visible in bright light conditions. Interview 22: "*There used to be a lot of glare off the old fashioned EFIS screens, so you couldn't see them…on the (*Boeing*) 777, it's like a laptop display almost, so effectively, even with bright sunlight you can still see quite clearly what's on the screen*".

FOIs described an annoyance if the aircraft visors were not properly maintained and would tend to use sunglasses more on these occasions. Visors were often seen as the primary eye protection aid; sunglasses were then used in situations where the pilot felt the visors were not able to provide sufficient light attenuation. There were more positive remarks made concerning the Airbus sun visor system compared to that of the Boeing fleet.

4.5.2.3 Adaptation to aircraft protection system

Some practices to protect the pilot from sunlight were described which involved a form of adaptation to the existing fitted aircraft visor system. These would take the form of newspapers, charts, tray liners or semi-opaque plastic sheets either stuck against the windshield or attached to the lowered visor (with spring clips or elastic bands) to increase the area of windshield blocked to the sun. This practice was reported only to carried be out in cruise with traffic collision avoidance system (TCAS) active and generally during long haul flights when pilots may be more fatigued and in circumstances of flying towards a low sun. It was also reported as a method used to reduce temperature in the cockpit. It was felt to be an older practice and was declared only by airline transport pilots.

4.5.2.4 Other practices

A number of other practices were described to shield the eyes from bright sunlight. These included the use of baseball caps. This was a preferred protection method for helicopter FOIs where there may be little or no protection offered in the aircraft. Additionally, the peak of the baseball cap could offer a complete blocking of view of direct sun and reduce any distraction from light flicker of sunlight passing through the helicopter rotor blades. Some airline FOIs also reported baseball caps useful during climb and descent where charts and newspapers to block windows could not be used.

Another practice declared during cruise was to adjust the seat so that the sun was less in the pilots' eyes. This may entail moving the seat to place the sun behind part of the aircraft structure or visor. Some FOIs felt that this was an unsafe practice as the pilot would lose full range of control movements and alter the visual aspect over the cowling. Further practices reported included using hand or fingers to obscure direct sunlight or eyelid squinting or avoid looking into the sun.

Some police helicopter FOIs used helmets that incorporate an integral visor which could be employed when required.

4.5.2.5 General

Aircraft visors were often seen as the primary eye protection strategy. Interview 1: *"I'm not a huge sunglasses fan. Good sun visors with good mobility on them – those are very important and decent blinds around the side of the aircraft to cut ambient light levels if required*". It was felt that visors were more effective than sunglasses in direct bright light, but that the glare source may not be covered by a visor. It was also felt that visors reduced lookout ability.

It was commented that sunglasses may help detecting ground features and other aircraft but detract from seeing instruments. It was felt that there is no ideal solution that works for all situations. FOIs felt that protection from sunlight involved compromise and pilots would manage sunlight as they would other aspects of flight management. Interview 3: *"everything has to be done at an appropriate time. I suppose 75-80% of the time, the actual designed sun visors are sufficient and other times you've got to be a little bit more ingenious…or put your sunglasses on, which is what I tend to do".*

4.5.3 Observed practices

As Flight Operations Inspectors, the pilots interviewed in this study flew with various airlines and pilots as part of their role. Both extremes of sunglass use (never used to full time wear) were observed in other pilots during day flights. One pilot was observed with different sunglasses for low altitude and cruise. Clip on, flip up sunglass shades were observed as well as a pair of sunglasses worn over a pair of prescription clear glasses.

The use of newspapers or charts to block out sunlight during (long haul) cruise was seen, but less so with time. This may be due to an improvement in aircraft visors or because the presence of a CAA inspector on board discouraged it. It was recognised by 4 participants as not best practice although it was not considered an impact to flight safety in that controlled environment.

4.5.4 Eye health

When questioned, 17 of the 22 interviewed did not express any anxiety or concern over the possibility of sunlight causing eye health problems. Three responded affirmatively and the remaining two did not give a definitive answer. FOIs flying infrequently or those flying low level (helicopters) did not have eye health concerns.

Of the three FOIs who did have health concerns, two said that they were developing a cataract and that they were subsequently more concerned of their eye health because of this. Additionally, two FOIs declared an assumption that the aircraft windshield would offer the required level of eye protection.

Some FOIs reported that they had other, non eye-related health concerns through flying such as sunlight exposure to skin, vibration and noise induced hearing loss. Interview 7: *"I've always throughout my career had attention on my hearing, always have earplugs in and ear defenders on flight ramp area, but no one has ever, ever said anything about sunglasses. I was issued sunglasses in the military, but we just thought that was cool because you just walked around with these military shades on – never really picked up that they were there for a purpose which is to protect eyesight in the long term apart from the short term alleviation of being able to see when you are flying"*.

4.6 Interview discussion

FOIs describe both disability and discomfort glare during flight. The use of eye protection strategies (e.g. sunglasses) is initiated by subjective symptoms of glare. Overly bright glare conditions act as a disruptive factor to a pilot's operational workload although it was not considered a flight safety hazard.

Modern aircraft are described as being better equipped in terms of visors and instrumentation for bright light conditions. More flexible use of visors and sun blinds offer a larger area of sun protection including sunlight from the side of the aircraft. The screen of an LCD display reflects a lower proportion of incident light compared to a glass or plastic screen in front of an analogue display. Therefore, the advent of LCD instrument displays reduces the level of sunlight reflection from instrumentation making these more visible and quicker to interpret by the pilot (Figure 4-a).

Figure 4-a Typical primary and secondary LCD flight displays. Note window reflection in lower part of left hand display due to position from photo was taken. This would likely be reduced from pilot seated position.

There are some aircraft where sun glare protection is minimal or non-existent. Often, these aircraft operate for short duration and at low level where UV and blue light hazard levels are likely to be low. However, one type of flight operation where exposure may be high is for the business jet pilot flying at high altitudes in an aircraft with little or no visor protection.

Sunglasses appear to be worn only a minority of time. When sunglasses are used, it is primarily for visual comfort (to reduce discomfort glare) and on occasions to aid visualisation of the task (to reduce disability glare). Sunglasses are not primarily worn by the FOI for solar radiation protection or eye health considerations. Additionally, the sunglasses used by the FOI to reduce disability or discomfort glare may not offer optimum solar protection.

Aircraft visors are often considered the first choice aid to manage glare within the cockpit. Although visors will shield the eyes from a direct glare source, there is not total windshield coverage and there could still be high levels of UV and blue light present within the cockpit.

Sunglasses are likely to be the optimum method to control the amount of UV and blue light hazard radiation entering the eye. One reason given for not using sunglasses during flight was due to the perceived reduction of visibility of aircraft instruments when viewed through a tinted sunglass lens. Light reaching a pilot's eye from below (such as reflected light from cloud top or snow) is likely to be largely blocked, in the case of an airline transport pilot, by the aircraft structure and instrument cowling. Therefore, the use of a graduated tint should aid instrumentation visibility. However, no participants were found to be using this type of tint.

Those interviewed in this study are experienced pilots. This may not be representative of the entire professional pilot population and younger pilots may express different views or have other concerns. The view expressed from those interviewed was that with experience the increase in workload associated with challenging conditions was easier to manage. This may mitigate against the apparent reduction of sunglass use in the older pilot as corrective glasses are required and the tendency for the older eye to be more likely affected by glare (section 2.4).

It appears that the requirement for wearing corrective glasses is a major factor as to whether a sunglass tint is used by pilots. Those FOIs who have worn spectacles throughout their flying career often feel to be disadvantaged in using sunglasses. A number of FOIs interviewed had ceased using sunglasses since the advent of their need for corrective spectacles. This is particularly surprising since glare problems from sunlight are likely to increase with age. The interviews show that sunglasses assist at alleviating glare and that the reduced use of sunglasses (or tinted prescription glasses where a pilot requires prescription spectacles) is associated with increased problems from glare, and potentially an increased risk of ocular pathology associated with light exposure.

4.7 Questionnaire introduction

The results of the series of interviews enabled a detailed insight into the issues of sunlight and the range of eye protection strategies used or observed by experienced pilots operating a wide range of aircraft types including large and small commercial jet aircraft, turboprops, business jets and helicopters. These exploratory semi-structured interviews allowed a range of solar protection strategies, some previously unknown, to be catalogued. These data informed the development of the questionnaire for a larger number of participants to complete.

4.8 Questionnaire method

The questionnaire was designed to ensure data were anonymous. Data collected included the pilot participant’s flying experience: age, type of flight currently undertaken, number of flying hours completed in the last year, previous types of flight undertaken and the number of years that the professional licence had been held. This latter question was posed at the beginning (single choice from six ranges) and, with different wording, near the end of the questionnaire (open text box) in order to gain a measure of intra-observer reliability.

The interviews revealed that the use of corrective glasses influenced the use of sunglasses. Therefore, participants to the questionnaire were also asked whether they were required to use spectacles for certificatory purposes and whether contact lenses were used.

The questionnaire contained a number of logic questions where the participants were asked further targeted questions depending on previous responses. For example, where the participant declared never using sunglasses, a further question was posed exploring their reasons with free text box for comments. For those that used sunglasses for any part of the flight, a further series of questions was triggered exploring the stages of flight or prevailing conditions for which they may be used, the style, age, tint and make of sunglasses and whether more than one pair of sunglasses were used in flight. Similar logic rules were used for ascertaining in those pilots who required prescription correction, whether clip-on sunglasses or contact lenses were used in flight and whether those contact lenses were known to have a UV block.

The pilots were asked to rate their sunglasses in a series of categories including comfort and performance. Pilots were also asked to rate the importance of various factors including UV protection and brand in sunglass selection. All participants completed a series of questions on the use of other eye protection strategies such as the fitted visors and blinds within the cockpit. Interviews revealed a range of strategies used and it was noted that some of these were used rarely. Based on this, a Likert-type score was devised which was weighted towards more infrequent use in order to elicit optimum responses from participants of all protection strategies used. There were eight categories used for estimation of percentage of time during flight that particular strategy used: 0%, <5%, 5-10%, 10-30%, 30-50%, 50-70%, 70-90%, >90%.

Pilots were asked to rate the instance of their subjective symptoms of discomfort glare and disability glare. Finally, all participants were asked about any known UV related eye pathology (such as cataract) and their awareness of the role of diet in the maintenance of eye health.

The questionnaire was piloted to a group of 18 CAA staff who were professional pilots employed as test pilots, flight crew standards inspectors or flight examiners. Additionally, one respondent was a professional pilot at the British Airline Pilots Association (BALPA). This group were given the link to the on-line questionnaire and, following explanation of the project aims, were asked to give feedback (both positive and negative), and to highlight any areas that were felt to have been omitted, spelling errors and any questions that were not clear or that they would prefer not to answer. The group on whom the questionnaire was piloted were informed that their responses would not be included in the final data analysis and they were encouraged to not necessarily document their own experience but to try different answers to elicit the full range of available questions.

Feedback was received from 14 pilots. Following collation of these comments, some changes were made. These included more detailed questions of previous experience including military flying and changing ‘commercial pilot’ to ‘professional pilot’ to encourage questionnaire completion by both commercial and airline transport pilots. Additional categories for using prescription sunglasses, rimless frames and using sunglasses during aircraft walk around were added to the relevant questions and a question targeting pilot rating of sunglasses was split into separate questions centred around performance and comfort. Comments were received that the questionnaire took less time to complete than originally stated in the introduction (10-15 minutes) and this was subsequently amended together with the correction of typographical errors.

Following these changes, it was felt that a second pilot would be beneficial. A further group of 21 professional pilots at the CAA (mainly participants in the original interviews) were invited to comment in the same way on the revised questionnaire. Feedback was received from 12 pilots. Minor suggestions were received, some of which were incorporated into the final version of the questionnaire. Most feedback received was very positive.

BALPA is an organisation representing the interests of professional pilots. Around 8,800 professional (mainly airline) pilots in the UK are members of BALPA (personal communication R. Hunter 07/02/12). As it was felt important that pilots should feel free to express any eye protection practices used and that no identifiable information would be requested, instead of using the CAA medical database to approach potential participants, the questionnaire was presented as a research study through London South Bank University and the Institute of Optometry. BALPA were approached and agreed to promote the questionnaire to all of their members using an e-mail invite from the chair of the BALPA Health and Safety group with a link to the survey. The first invite was sent on the December 2012 with a follow-up reminder sent in February 2013. The questionnaire is presented in appendix L.

Data analysis was carried out using IBM SPSS v.19 and Microsoft Excel 2007. Data were initially subject to descriptive and frequency analysis. Where the mean age of respondents in two groups or categories is compared, the independent T-Test is used as age data is considered to be parametric. Similarly, where there the mean of more than two categories are compared, one-way ANOVA analysis is conducted. Pearson's chi-square test is conducting for analysis comparing sets of categorical data. Where comparison of two independent groups of non-parametric or ordinal data is conducted, the Mann Whitney U test has been used are where there are more than two independent groups compared, the Kruskal-Wallis test has been used.

The Spearman rank-order correlation test has been used to assess the association between two sets of ordinal data. Analysis of covariance (ANCOVA) has also been conducted in order to assess the difference in means between two groups whilst controlling for the effect of age (confounding variable). Responses in free text boxes have been subject to content analysis and categorisation into new variables which were in turn subject to descriptive and frequency analysis. The level of statistical significance used is $p<0.05$.

4.9 Questionnaire results

4.9.1 Participant demographic

A total of 2,967 questionnaires were submitted which constituted a response rate of 33.7% (total BALPA membership 8,800). Fifty pilots partially completed the questionnaire but omitted a required field. These incomplete records were not included in the analysis. This represents a 98.3% completion rate and the results of 2,917 questionnaires were analysed. Figure 4-b shows a histogram of the age of the study participants. The mean age was 42.6 years (SD 9.7 years) in the age range 20-66 years. The age distribution is approximately normally distributed (skewness 0.02). The two participants age 20 had less than 1,000 flying hours and would have been flying on a frozen ATPL, which would be validated to a full ATPL once 1,500 flying hours were achieved and the pilot was a minimum age of 21 (CAA, 2013). The four participants over 65 were not involved in airline transport flight operations.

The mean length of time respondents had been professional pilots was 16.9 years (range 1 to >40 years) with 91.6% having a total flight time logged over 2,500 hours (Figure 4-c).

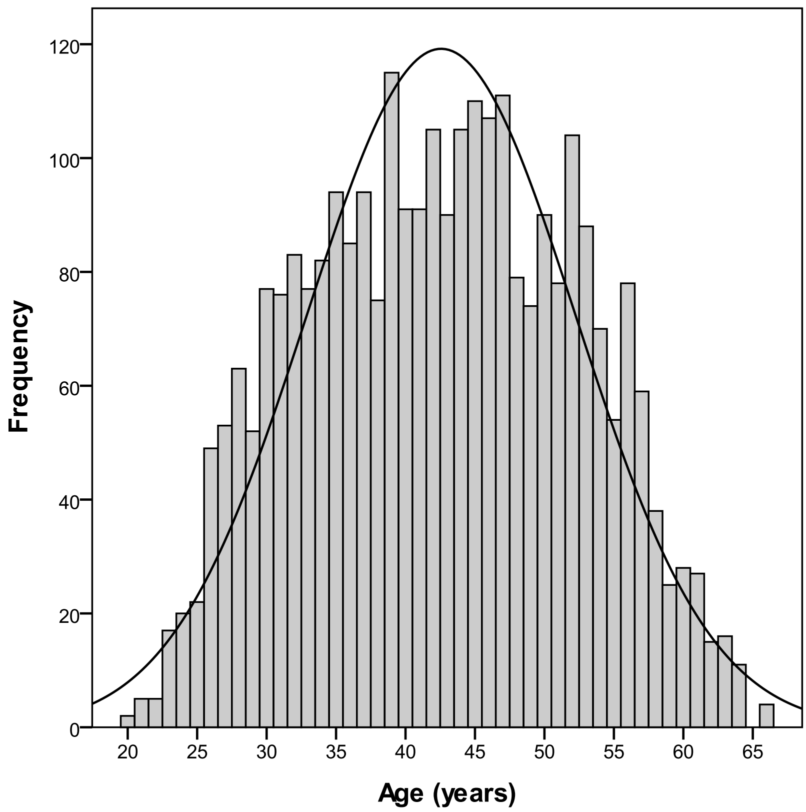

Figure 4-b Age distribution of participants. The curve shows a normal distribution

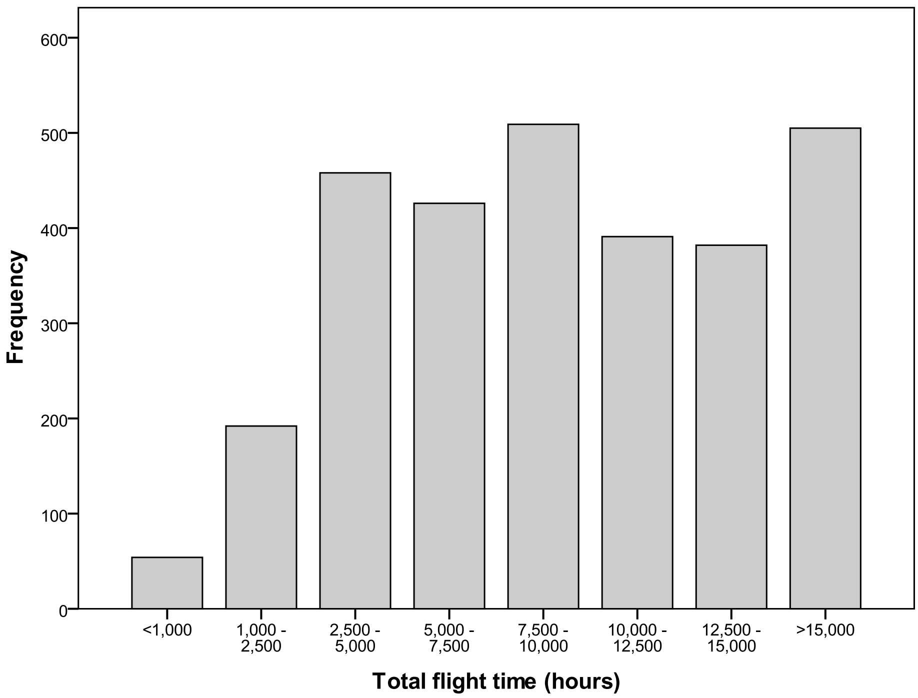

Figure 4-c Flight experience of participants.

The majority of respondents (92.5%) operated on either airline transport short haul (n=1711) or long haul (n=986). A further 54 (1.9%) respondents operated helicopters off shore and 44 (1.9%) flew aeroplane cargo flights. Other categories included business jet, charter work, instructor and police/air ambulance helicopter each of which constituted less than 1% of the respondents.

Participants were questioned regarding their previous flying experience. Responses to more than one category were permitted. 1041 (35.7%) pilots declared no other previous type of professional flying undertaken. 738 (25.3%) pilots had previous short haul airline transport experience (mainly from the long haul airline transport pilot group) and 372 (12.8%) pilots had previous long haul airline transport experience (mainly from the short haul airline transport pilot group). 694 (23.8%) pilots had previous experience as flying instructors (646 aeroplane, 42 helicopter, 6 both) and 546 (18.7%) pilots had previous military experience (378 aeroplane, 116 helicopter, 52 both). Other categories declared included aeroplane charter (320, 11%), aeroplane aerial work (including aerial photography, banner towing, crop spraying) (237, 8.1%), aeroplane cargo (229, 7.9%), aeroplane business jet (123, 4.2%), helicopter off-shore (49, 1.7%), helicopter charter (42, 1.4%), helicopter aerial work (34, 1.2%) and helicopter police/air ambulance (29, 1.0%).

Participants were asked about their total flying hours accrued over the previous year (Figure 4-d). The mean was 647 hours and 79.7% of pilots had logged more than 500 hours. Two respondents declared accruing 1,000 hours yet the limit for professional pilots is 900 hours per annum (Civil Aviation Authority, 2003). Within short haul pilot group, the mean number of hours flown in the previous 12 months was 640 hours (SD 151 hours) and in the long haul pilot group, the mean was 707 hours (SD 150 hours).

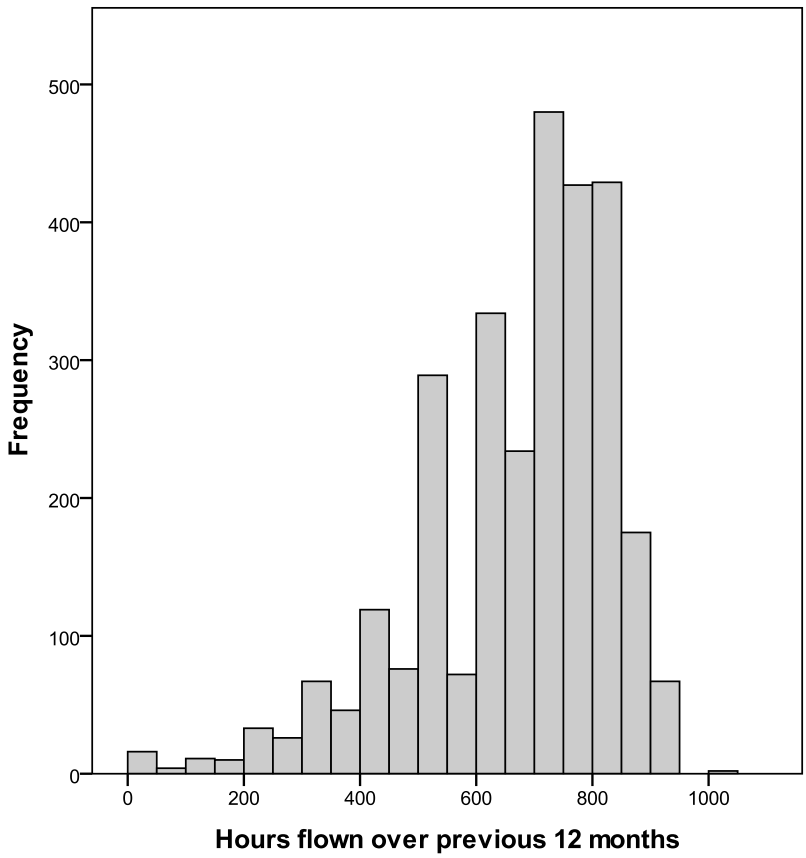

Figure 4-d Number of hours flown over the previous 12 months.

4.9.2 Use of corrective spectacles

A total of 1332 (45.7%) pilots had a requirement for corrective spectacles to be worn on their medical certificate (VDL). Within this group, 489 (36.7%) had always had this endorsement on their medical certificate; 397 (29.8%) had the endorsement placed on the medical certificate in the previous 5 years, 235 (17.6%) had the spectacle endorsement for between 5-10 years and 211 (15.8%) had the endorsement for over 10 years. Pilots with lower flying hours were significantly more likely to have always had a VDL present on their medical certificate as determined by one-way ANOVA ($F=141.7$, df 3, $p<0.001$). This is likely to relate to changes to medical standards and is discussed in section 4.11.1.

To assess any differences between various types of professional flying, the most prevalent three categories were analysed: aeroplane airline transport short haul (SH), aeroplane airline transport long haul (LH) and helicopter off-shore (HOS). The fourth most prevalent category, aeroplane cargo, was not included as this type of flying would generally be carried out on similar aircraft type as SH or LH operations and in similar conditions with the exception that cargo pilots would most likely be involved with a greater percentage of night flying.

Assessing the prevalence of a spectacle requirement within the three main flying categories, Pearson chi-square analysis showed a significant difference with SH significantly less likely to require glasses than LH and HOS (X^2=9.2, df 2, p=0.007) as seen in Table 4-a.

	Requirement for optical correction		
Type of flying	**Yes n (%)**	**No n (%)**	**Total**
Airline long haul	486 (49.3)	500 (50.7)	986 (100.0)
Airline short haul	737 (43.1)	974 (56.9)	1711 (100.0)
Helicopter off-shore	26 (48.1)	28 (51.8)	54 (100.0)
Total	**1249 (45.4)**	**1502 (54.6)**	**2751**

Table 4-a Prevalence of a spectacle requirement in different flying categories.

However, one-way ANOVA analysis with multiple comparison tests showed that the mean age of SH pilots was significantly lower than both LH and HOS groups (F=88.3, df 2, p<0.001). There was no significant difference in the mean age of LH and HOS groups. It is probable that the difference in spectacle requirement between the flying categories is largely affected by the difference in age between the groups. Figure 4-e shows the distribution of spectacle and non-spectacle wearing pilots with age. Spectacle wearers were significantly older than non-spectacle wearers (independent T-Test = 17.1, df 2892, p<0.001).

Of the spectacle wearers, 24 (0.8%) used clip-on shades over their prescription glasses; 355 (26.6%) wore contact lenses during flight and of this group, 110 (30.9%) wore contact lenses with a UV block, 101 (28.4%) had no UV block and 144 (40.6%) did not know if their contact lenses included a UV block.

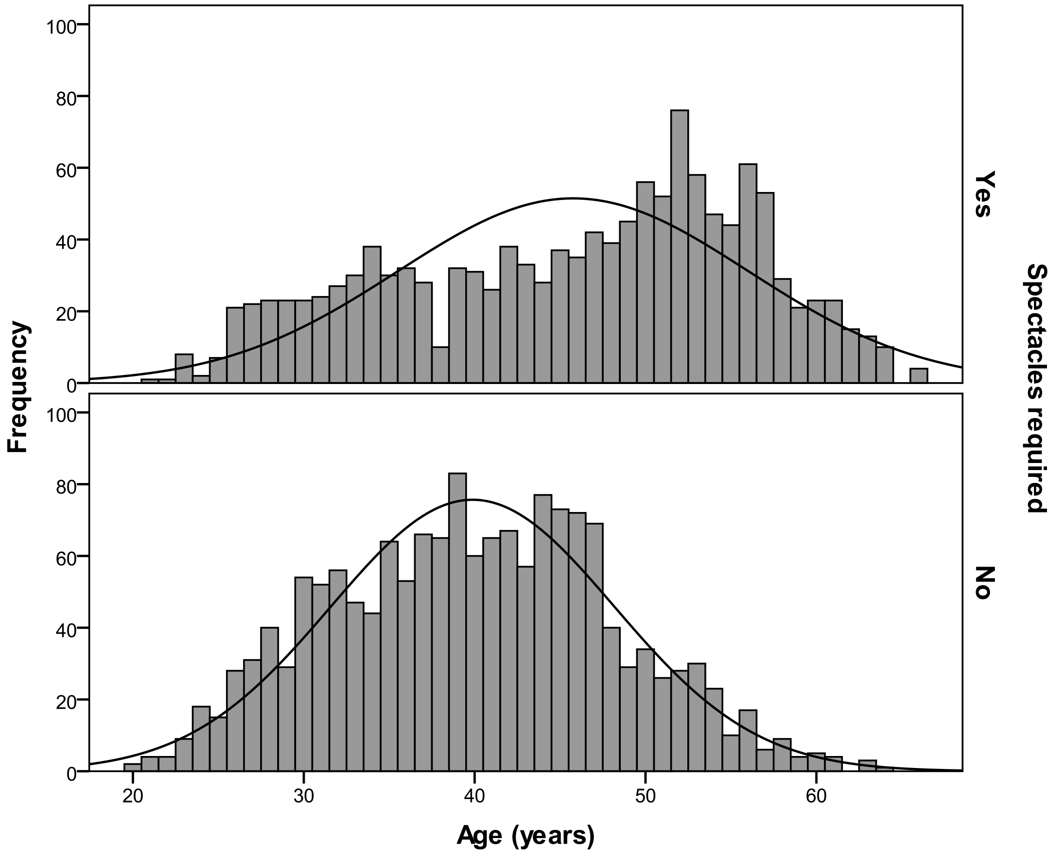

Figure 4-e Age distribution of spectacle and non-spectacle wearers. Distribution curves show a relative negative skewness towards higher age in spectacle wearers.

4.9.3 Sunlight on the flight deck

Pilots describe conditions where they need to look outside through the cockpit windshield and where the azimuth of the sun is such that it is near their line of sight as being difficult to manage. This was independently reported in free text boxes by participants during separate questions regarding the prevalence of discomfort and disability glare symptoms. Glare symptoms were reported either during the critical stages of flight including take-off, approach and landing (n=10 for discomfort glare and n=27 for disability glare) or when flying in the direction of the sun at sunrise or sunset (n=36 for discomfort glare and n=15 for disability glare).

70: *'Did have to do a go around recently because I was blinded by sun appearing from behind cloud and I could not get my sunglasses on in time. Was as if I had a laser shone in my eyes!'*

190: *'Landing directly into the sun is the worst case scenario, especially in haze and on a visual approach as we are sometimes require* (sic.) *to do'.*

These comments concur with the results from the interviews with FOIs in section 4.5.1 where the similar challenging sunlight conditions were described.

Twenty six (0.9%) pilots independently reported eyestrain and headache (symptoms known as asthenopia) in bright light conditions, 14 (0.5%) reported sensitivity to light and three (0.1%) reported symptoms of 'eyes watering'. A further eight pilots (0.3%) stated that bright sun caused sneezing.

During instances of disability glare, pilots independently reported in free text boxes that aircraft instruments were not sufficiently visible (n=40, 1.4%), that the use of sunglasses dimmed the view of the aircraft instruments making them hard to interpret (n=27, 0.9%), that more modern LCD instrument displays were easier to interpret than CRT displays in these conditions (n=9, 0.3%) or that contamination (dust, finger marks) became more apparent making displays hard to interpret (n=9, 0.3%). Pilots also independently reported strategies, including the use of sunglasses to reduce discomfort glare (n=53, 1.8%) and disability glare (n=61, 2.1%).

Two comments were also received from pilots who appreciated a sunny environment:
204: *'I fly to the rigs in the North Sea. We actively seek the sun!'*
2320: *'I live in Scotland - it's good to see the sun sometimes!'*

4.9.4 Use of sunglasses

When questioned about the overall percentage of time sunglasses were used during flight, no clear consensus was achieved with similar numbers of respondents in each category (Figure 4-f).

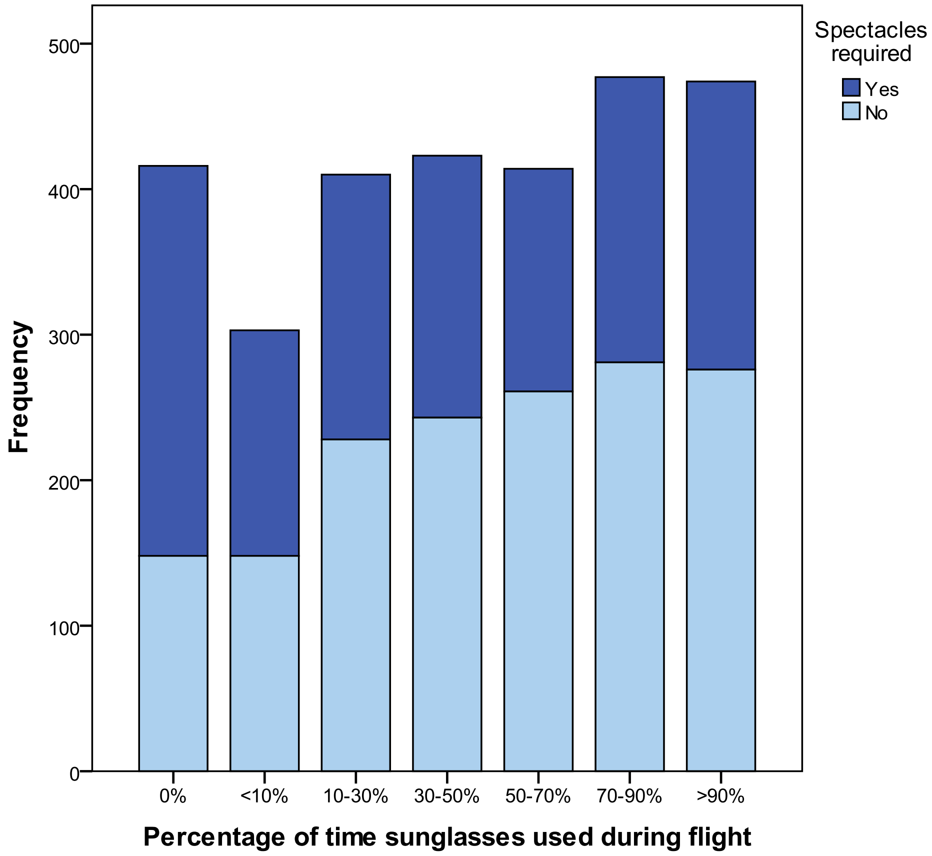

Figure 4-f Distribution of amount of sunglass use during daytime flight for spectacle and non-spectacle wearers

A total of 727 (24.6%) of participants never use sunglasses or use less than 10% of the time during flight. Spectacle wearers were found to use sunglasses significantly less compared to non-spectacle wearers (Mann-Whitney U, $p<0.001$). Sunglasses were used significantly more by different flying categories: SH>LH>HOS (Kruskal-Wallis, $p<0.001$) and SH>LH (Mann-Whitney U, $p<0.001$). HOS pilots were least likely to wear sunglasses.

Ex-military pilots use sunglasses significantly less than those pilots without a military flying history (Mann-Whitney U, $p<0.001$), however they were more likely to be spectacle wearers (Mann-Whitney U, $p<0.001$) and to be older (independent T-Test with variances not equal, $t=26.1$, df 1155, $p<0.001$). Although it is likely that this difference in mean age and spectacle use between the two groups will affect sunglass use, a free text box comment from one ex-military pilot may reveal one reason for a lower sunglass use within the ex-military pilot group:

725: '*As a young military helicopter pilot I never gave sunlight much thought, in fact it may even have been macho not to use the tinted visor on the helmet or to use* *sunglasses. I have therefore used sunglasses very little during my life - even outwith the aviation environment...'*

Of the 413 (14.2%) of pilots who never use sunglasses during flight, significantly more required corrective spectacles - VDL (269) compared to those who did not (148) (Pearson chi-square, X^2 = 69.6, df 1, p<0.001). The reason for not using sunglasses was explored within this group of pilots (Table 4-b).

Reason given	**Spectacles required (n=269)**		**No spectacles required (n=148)**	
	Number	**% within group**	**Number**	**% within group**
Aircraft has adequate protection offered with	102	37.9	57	38.5
I forget to carry them with me	17	6.3	20	13.5
I wear clear prescription glasses instead	115	42.8	8	5.4
Sunglasses too expensive	18	6.7	12	8.1
Sunglasses uncomfortable	36	13.4	53	35.8
Sunlight doesn't bother me	60	22.3	48	32.4
Too much hassle to put on during flight	44	16.4	41	27.7
Instruments too dark through sunglasses	37	13.8	21	14.2
Sunglasses not used for other reasons	26	9.7	6	4.1

Table 4-b Reasons given as to why sunglasses are not used. Groups split into spectacle wearers and non-spectacle wearers. Each response is also given as a percentage of the total in that group. Participants may have given multiple responses.

Non-spectacle wearers are more likely to forget to take their sunglasses onto the flight deck or find their sunglasses uncomfortable to wear than spectacle wearers. It can be seen (Table 4-b) that eight respondents who do not require spectacles claim that a reason for not using sunglasses in flight is due to wearing untinted prescription spectacles. This small group is likely to consist of pilots with low optical prescriptions who are able to meet the vision standards without their spectacles but who use them in flight for optimum visual acuity or visual comfort.

Further independent comments were received from both sunglass wearers and non-sunglass wearers regarding barriers to successful sunglass use:

2239: *'It is always difficult to find glasses which give adequate protection and yet still allow you to clearly see the instruments at the same time. The right style of frame is also vital to avoid discomfort sobs* (sic.) *the temples and ears while wearing a headset. These of course cannot be tested while in the shop pre purchase. Difficult, and costly if you get it wrong, which i have many times!'*

2386: *'Glasses often have to be worn for hours at a time with headsets, so can get uncomfortable. Glasses for me have to protect from the cockpit environment as well as sunlight. Zonal driers and very powerful air conditioning across the windshield dry out eyes'.*

2640: *'Just the combination of Headsets and sunglasses make for a difficult environment, either your ears or your eyes are going to lose out!'*

2777: *'I used to wear wrap around lenses but found the appearence* (sic.) *to ""robotic"" and for CRM* (Crew Resource Management) *purposes changed styles'*.

2836: *'The biggest barrier to me using sunglasses in the flight deck is because I wear glasses. As you enter/exit cloud and light levels rise/drop the time taken to change from glasses to sunglasses whilst hands-off/heads-down is very distracting and as such I usually end up squinting or using the aircraft screen'*.

The majority (1706, 58.9%) of pilots used sunglasses between 10-90% of the time. All sunglass users were questioned as to what phase of flight and the conditions under which sunglasses were worn (Figure 4-g). Altitude cruise, which is usually the majority of the flight time, was the stage of flight where sunglasses were most likely to be used (mode: 'usually', n=1070, 43.1%), however the use of sunglasses was driven more by perceived bright light conditions rather than a particular phase of flight (when flying towards the sun, mode: 'always', n=1326, 53.4% , when it feels too bright, mode: 'always', n=1381, 55.7%).

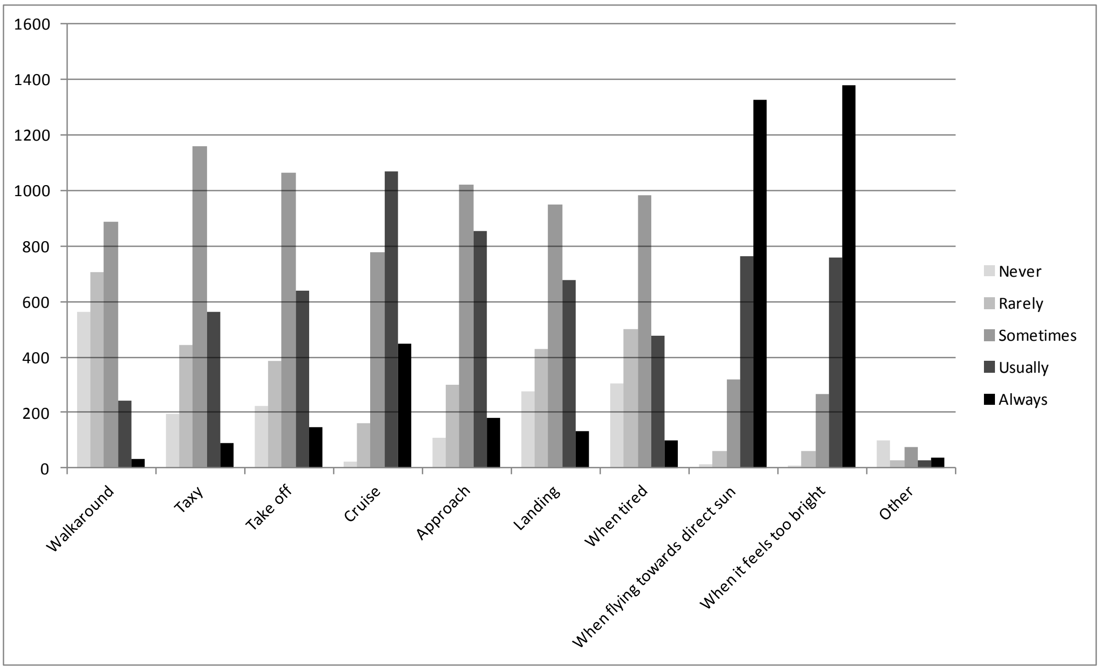

Figure 4-g Variation in sunglass use with different stages of flight and prevailing sunlight conditions.

Other conditions given where sunglasses were used (n=51) included where light is reflected from cloud tops (n=19), to help pilot improve visual perception (n=9), where aircraft visors not sufficient to reduce light levels (n=3) and when trying to spot other traffic or landmarks (n=2).

A total of 110 (4.4%) respondents used a second pair of sunglasses. These were used less in all categories (lower Likert scores) however showed a similar pattern in that they were used most during cruise and in bright light conditions. Pearson chi-square analysis revealed that spectacle wearers were more likely to use a 2nd pair of sunglasses (X^2=12.9, df 1, p<0.001). This could be due to using prescription and non-prescription sunglasses when using contact lenses. There was no significant difference in the use of 2nd sunglasses between contact lens wearers and non spectacle wearers (Pearson chi-square) with both groups most likely to use 1 pair of plano (non-prescription) sunglasses. Table 4-c shows that LH pilots were more likely to use 2 pairs than SH or HOS pilots (X^2=27.0, df 2, p<0.001). Kruskal-Wallis analysis revealed no significant difference between those using 1 or 2 pairs of sunglasses and the use of any other eye protection strategy (such as aircraft visor).

Type of flying	Two pairs of sunglasses used Yes n (%)	No n (%)	Total
Airline long haul	59 (7.2)	764 (92.8)	823 (100.0)
Airline short haul	40 (2.7)	1460 (97.3)	1500 (100.0)
Helicopter off-shore	1 (2.3)	42 (97.7)	43 (100.0)
Total	**100 (4.2)**	**2266 (95.8)**	**2366**

Table 4-c Prevalence of use of second sunglasses in different flying categories.

When questioned as to the difference between first and second pair of sunglasses, 113 responses were gained (participants were offered multiple responses); 45 (39.8%) stated that one pair of sunglasses were prescription, 33 (29.2%) stated a difference in tint depth, 18 (15.9%) a difference in frame style, 7 (6.2%) a difference in tint colour, 5 (4.4%) had polarised lenses for 1 pair and 3 (2.7%) used other sunglasses to aid comfort with their headset. The remaining 2 responses gave other explanations.

Respondents were also questioned if their sunglass use had altered over the past year. This was to gain insight as to external factors which may influence the use of sunglasses. A one year period was chosen as it was anticipated that it would be easier for the respondents to recall any changes over the recent past. The reasons given are presented in the Table 4-d.

The most common cause of reduction in sunglass use was a change to prescription. Through coding of a free text comments box, this group was mainly emmetropes who had become presbyopic and required near correction (presbyopia is a normal ageing process where the eye progressively develops a reduced ability for near focus. It typically starts to affect individuals around the age of 45 and people with previously good eyesight start to need reading glasses).
853: '*... Reading glasses prevent use*'.

The most common cause for an increase in use was through an increased awareness of the potential impact that exposure may have to vision:
1176: *'A Captain from a previous airline was diagnosed with cancer in the left eye and recently passed away (as a result of the cancer spreading). The cancer originated in his left eye and I remember when I worked with him, he almost never wore sunglasses during any phase of flight. He was 58 when he was first diagnosed'.*

Reasons for change in sunglass use	Declared use			Total
	Increase	Decrease	Same	
Sunglass tint	3	2	3	8
Sunglass comfort	7	9	0	16
Change of operating environment	20	18	2	40
Change of prescription	10	26	10	46
Increase awareness of potential impact to vision	23	1	4	28
Eye contact with other pilot	1	0	1	2
Lost / damaged sunglasses	1	4	1	6
Use other strategies instead	0	3	1	4
Visual fatigue	6	3	3	12
Other	0	2	1	3
Change to light sensitivity	6	3	1	10
Total	77	71	27	175

Table 4-d Reasons given as to a change in sunglass use. Participants who declared a change in use of sunglasses over the previous year were asked to state the previous amount of use and, in a free text box, describe the reason (if any) for the change of use.

Both increases and reductions in visual fatigue and light sensitivity were reported as reasons for change in sunglass use, although more pilots reported an increase in use (n=12) compared to a decrease (n=6). Overall, 44.4% reported an increase in use, 37.6% a decrease and 17.9% selected the same time category.

723: *'... with age my sensitivity to sunlight has increased - I notice this when driving as well and normally need sunglasses on even cloudy days'*.

853: '*Tolerance to bright light increased with age'*

Other changes to vision with age were also reported:

486: '*As I have got older I find it more difficult to transition from looking out with sunglasses on to looking in at the instruments. This has led to me wearing my sunglasses less so I have a better view of the instruments, even if this means squinting more'*.

Participants were asked a series of questions regarding the primary sunglasses used during flight (Figure 4-h). 56.6% reported their sunglasses to be between one to four years old. Those with a VDL had significantly newer sunglasses (Mann-Whitney U, p=0.002).

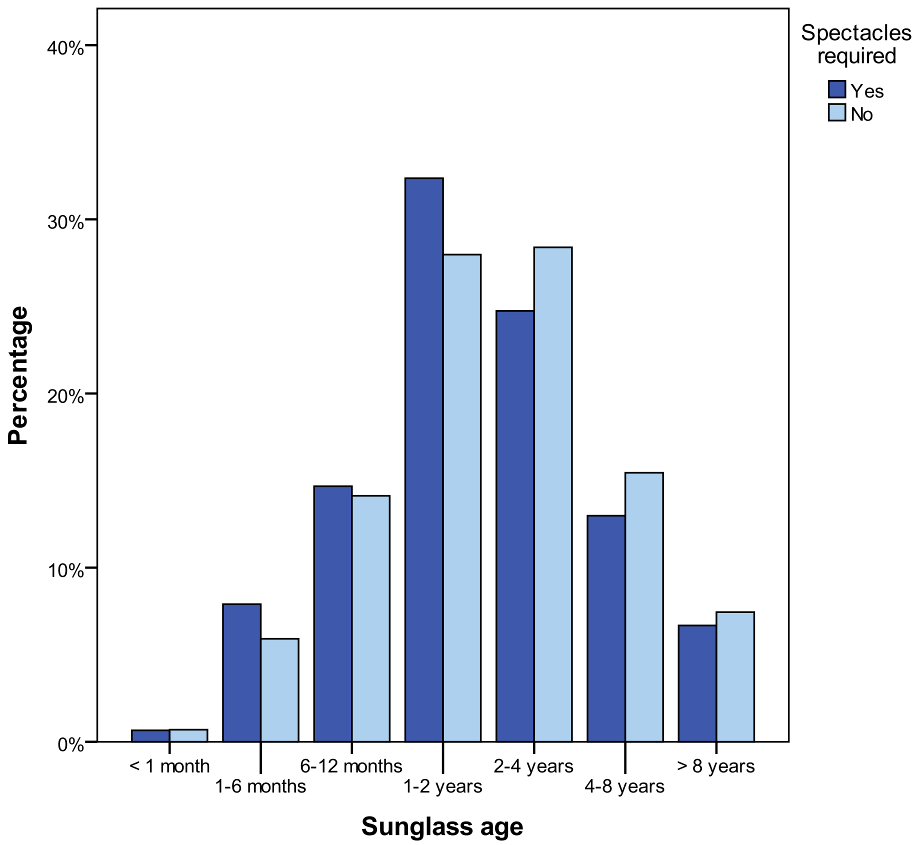

Figure 4-h Distribution of sunglass age in spectacle and non-spectacle wearers.

Of those respondents using sunglasses, 1903 (76.1%) had a fixed non-graduated tint, 278 (11.1%) had a graduated tint, 162 (6.5%) had polarised lenses and 73 (2.9%) had photochromatic lenses. A further 84 (3.4%) did not know what type of tint their sunglasses had. Pearson chi-square analysis revealed that LH pilots were significantly more likely to have a fixed tint compared to SH pilots (X^2=18.8, df 4, p=0.001).

Pilots most commonly described their sunglasses as having a grey (957, 38.3%) or brown (921, 36.8%) tint. 292 (11.7%) described a green tint, 40 (1.4%) yellow, 35 (1.2%) black and 46 (1.6%) blue. Other colour tints described (each less than 0.3%) included red, silver, gold, pink, purple, amber and orange however, it is recognised that perceived colour of tint is not a reliable measure of spectral filtering properties of a sunglass lens. This is discussed further in section 4.11.2.

The distribution of frame style within the three main flying groups is shown in Table 4-e. When the typical prescription spectacle frame styles (oval/round, rectangular and rimless) were grouped together, Pearson chi-square analysis showed that HOS pilots were significantly more likely to wear an aviator style sunglass frame (X^2=31.9, df 4, p<0.001). Overall, the most prevalent type of frame style was wrap-around (939, 37.6%), aviator (840, 33.6%) and rectangular (18.5%). 155 (6.2%) respondents had rimless sunglasses and 104 (4.2%) had oval or round frames.

	Frame style n (%)					
Type of flying	**Aviator**	**Oval/round**	**Rectangular**	**Rimless**	**Wrap-around**	**Total**
Airline long haul	220 (26.8)	35 (4.3)	165 (20.1)	54 (6.6)	348 (42.3)	822 (100.0)
Airline short haul	551 (36.7)	55 (3.7)	266 (17.7)	89 (5.9)	539 (35.9)	1500 (100.0)
Helicopter off-shore	23 (53.5)	3 (7.0)	3 (7.0)	4 (9.3)	10 (23.3)	43 (100.0)

Table 4-e Distribution of frame style within three main flying categories.

All sunglasses users were asked how long ago the fit of their sunglasses had been assessed or adjusted. 1861 (63.8%) had never had them fitted. 106 (3.7%) had the fit checked within the previous six months. Spectacle wearers were significantly more likely to have had their sunglass fit checked (Pearson chi-square, X^2= 528.0, df 1, p<0.001).

Respondents were asked to rate the overall performance of their sunglasses (Figure 4-i) and 132 (5.2%) rated their sunglasses ‘very poor’ or ‘poor’ while 1759 (70.4%) rated their sunglasses ‘good’ or ‘excellent’.

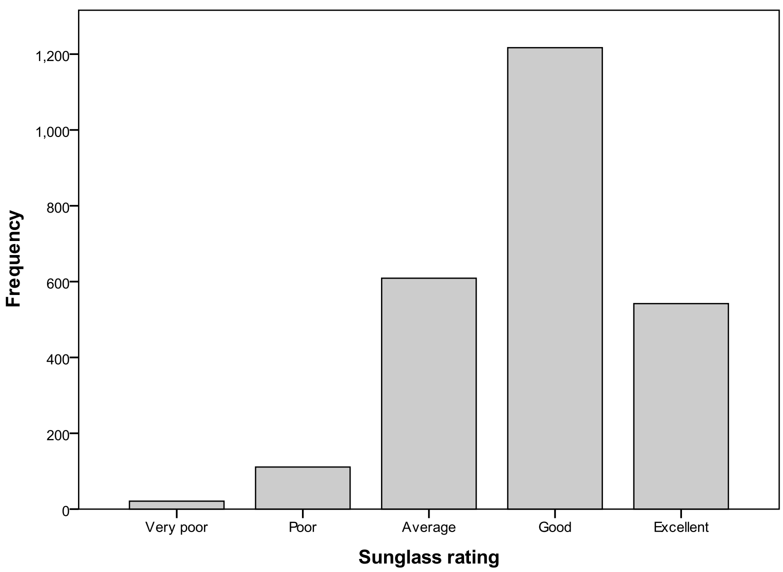

Figure 4-i Pilot rating of overall comfort and performance of sunglasses used in flight.

The overall sunglass rating was significantly higher amongst non-spectacle wearers (Mann-Whitney U, p=0.046). There was no significant relationship between overall sunglass rating and flying experience (Kruskal-Wallis) but a significant difference was seen with age with younger pilots rating overall performance higher than older pilots (one way ANOVA, F=4.6 df 4, p=0.001). There was no significant relationship between the overall sunglass rating and sunglass age, type or colour of tint or period since last fitted (Kruskal-Wallis). Additionally, there was no significant relationship between overall sunglass rating, sunglass age, colour of tint or when last fitted between LH-SH-HOS pilot groups (Kruskal-Wallis).

A total of 91 different sunglass makes were reported in addition to prescription sunglasses, non-brand sunglasses and store own brand sunglasses. Aside from the three major brands, other sunglasses reported were re-categorised into either 'aviation specific' where the manufacturer intended the sunglasses to be used specifically for aviation, 'marked for solar protection',' marketed for sports use' (usually cycling or skiing) or 'fashion marketed' sunglasses including designer labelled sunglasses. A summary is given in Table 4-f.

Sunglass category	Frequency	Percentage
prescription	402	16.8
Ray Ban	768	32.1
Oakley	458	19.1
Serengeti	205	8.6
aviation specific	41	1.7
marketed for solar protection	116	4.8
marketed for sports use	52	2.2
fashion marketed	207	8.6
store own or non-brand	141	5.9
other	4	.2
Total	2394	100.0

Table 4-f Summary of the distribution of sunglass make with re-categorisation of those sunglasses not within the most prevalent 3 brands into generic groups due to the wide variety of sunglass types declared.

59.8% of respondents used RayBan, Oakley or Serengeti sunglasses. Silhouette was the fourth most prevalent brand worn by 1.8% of respondents. There were a number of manufacturers who produced sunglasses specifically for pilots however only 1.7% of respondents used these. RayBan sunglasses were used more commonly within the HOS pilot group (42.5%) compared to SH (34.9%) and LH (26.5%) pilot groups.

Only 13.8% of the respondents used prescription sunglasses and 45.7% of pilots require refractive correction. If all contact lens wearers (who could be using non-prescription sunglasses) were excluded, there remain 33.5% of respondents using corrective spectacles. Therefore, a maximum of 41% of pilots with VDL use sunglasses.

Respondents were asked to rate the importance of a series of factors when selecting sunglasses (Figure 4-j). The mode score for comfort of frame, UV protection and comfort of tint was ‘very important’ (72.6%, 65.9% and 54.6% respectively). Sunglass brand was considered least important (mode: ‘not important’, 35.7%) and was significantly less important for spectacle wearers (Pearson chi-square, X^2=38.9, df 3, p<0.001).

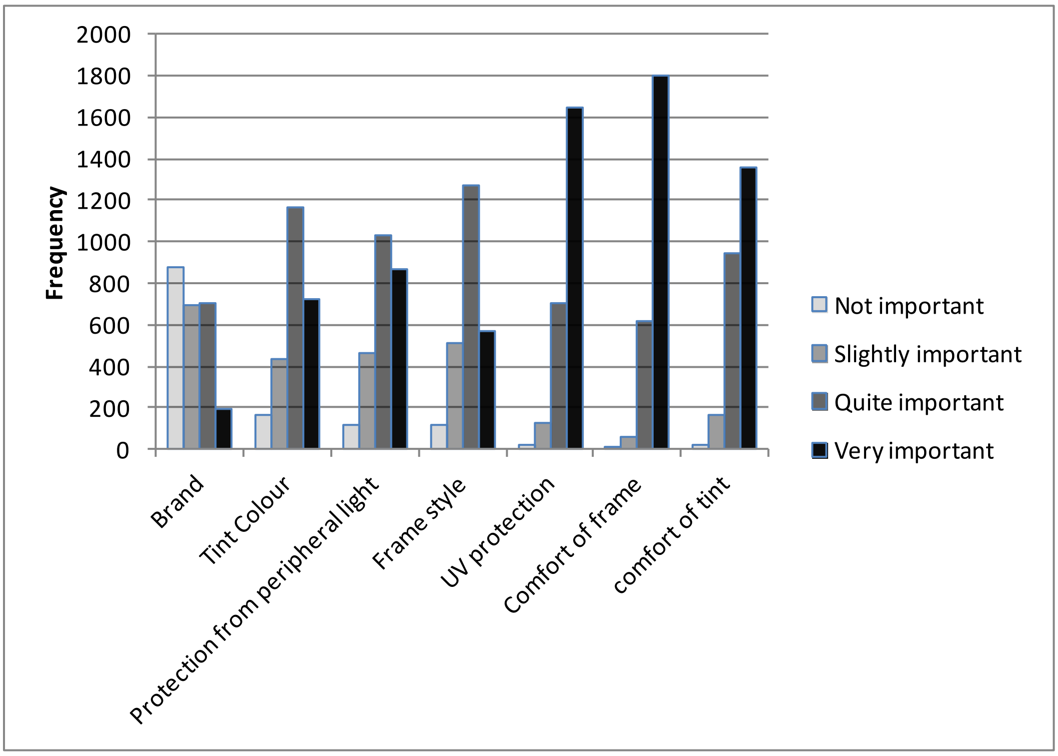

Figure 4-j Subjective importance ratings given by the pilot to various considerations for sunglass selection.

Frame style, UV protection and frame comfort were also significantly less important factors for spectacle wearers (X^2=18.0, df 3, p<0.001; X^2=11.4, df 3, p=0.010 and

X^2=8.0, df 3, p=0.046 respectively). There was no significant difference in the rating of tint colour, comfort of tint or protection from oblique or peripheral light between spectacle and non-spectacle wearers (Pearson chi-square). There was no significant difference for any ratings between LH-SH-HOS pilots (Pearson chi-square).

4.9.5 CAA guidance

Respondents were questioned as to whether they had reviewed CAA published guidance on sunglasses before purchasing. 2232 (89.3%) had not reviewed the CAA guidance material. Of those who had reviewed guidance and had commented, 1 gave a positive comment, 1 gave a negative comment and 1 referred to the US Federal Aviation Administration (FAA) guidance material.
1606: *'I read the CAA guidelines and had a custom fit pair of Oakley's made with the shading and transmission rates in accordance with these guidelines. They are superb'.*
2198: *'You asked if I looked at the caa guidelines, but not what I thought of them. Poor, vague, not much use. Tried asking an optician to explain them but couldn't'*.
1217: *'The caa should have a similar website to the FAA. The FAA make fabulous recommendations as to the tint shades that are available and what this pros and cons are of these'.*

Those requiring spectacles were significantly more likely to review guidance (Pearson chi-square, X^2=65.8 df 1, p<0.001). Additionally, the mean age of pilots reviewing CAA guidance was significantly lower (one-way ANOVA, F=25.3, df 1, p<0.001).

4.9.6 Glare symptoms

Respondents were asked to rate the prevalence of symptoms of discomfort and disability glare during flight (Figure 4-k).

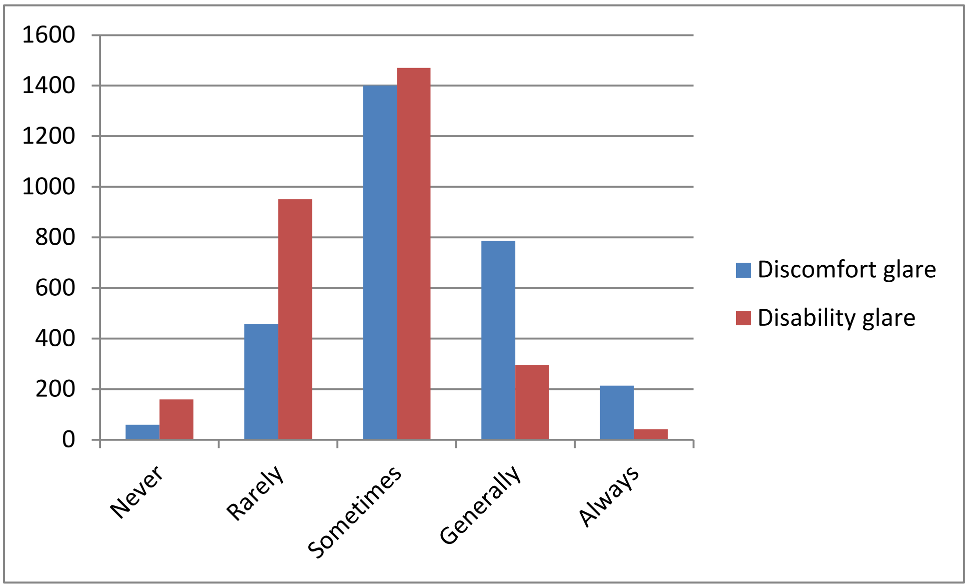

Figure 4-k Distribution of reported discomfort and disability glare during flight

Discomfort glare (visual discomfort caused by direct or reflected sunlight) was reported 'sometimes' or 'generally' by 74.9% of respondents. When it occurs, pilots report symptoms of headaches and asthenopia:

1270: '*Can't fly in day time without eye protection- causes eye strain / headaches*'.

1058: *'After a long period my eyes feel tired and can develop only what I could describe a twitch. This stops once rested or the sun sets'*.

1108: *'I get sore eyes from too much sun and very occasionally get conjunctivitis with too much exposure'*.

2904: '*When strong low sunlight is from side horizon. Up-sun eye is in direct bright light, down-sun eye is in deep shadow'.*

Disability glare (preventing pilot from visualising aircraft instruments) was reported 'rarely' or 'sometimes' by 83% of respondents. Disability glare was mainly reported during take-off, approach and landing:

1556: *'Generally only on take-off when the high pitch angle of the aircraft can result in the sun being just above the coaming* (sic.) *in direct line of sight, even when looking in at the instruments'.*

1759: *'This can be a problem during the critical stages of flight - for example of take-off/climb out when there is not time/the option to find glasses when they are not already in a handy position - ie, the priority is the safety of the aircraft'*.

2685: *'When turning into the sun, often the instruments are totally unreadable for a few seconds until your eyes adjust'.*

A number of pilots also gave details of their actions when presented by disability glare:

336: *'...occasionally primary displays during T/O and landing require one hand used as a shade to see, instead of the hand being on the controls!'*

545: *'Always wear a baseball cap for take off and landing'.*

2477: *'Wearing sunglasses proud of my face, while appearing a little odd, enables sight of the instruments while the glare for outside is obscured by the lenses'.*

2698: *'Sometimes it is only effective to hold your hand in front of your face'.*

There was no significant difference in the reporting of discomfort or disability glare between LH-SH-HOS pilots (Pearson chi-square). There was a significant positive correlation between reported discomfort glare and disability glare (Spearman's rho 0.431, $p<0.001$). There was no significant relationship between levels of discomfort or disability glare and age (one-way ANOVA) or total number of flying hours (Kruskal-Wallis). However, there was a significant increase in sunglass use with increasing reported levels of discomfort glare ($p<0.001$ Kruskal-Wallis) and disability glare ($p<0.001$ Kruskal-Wallis).

4.9.7 Other eye protection practices employed

Respondents were questioned regarding other eye protection practices employed during flight (Figure 4-l). Using the standard fitted aircraft visors was, by far, the most common strategy employed. The other strategies decreased in popularity score from use of newspaper or chart against windshield or visor followed by adjusting seat position, using hand to block direct sunlight, using tray-liners against windshield. The use of a peak (baseball) cap was least popular.

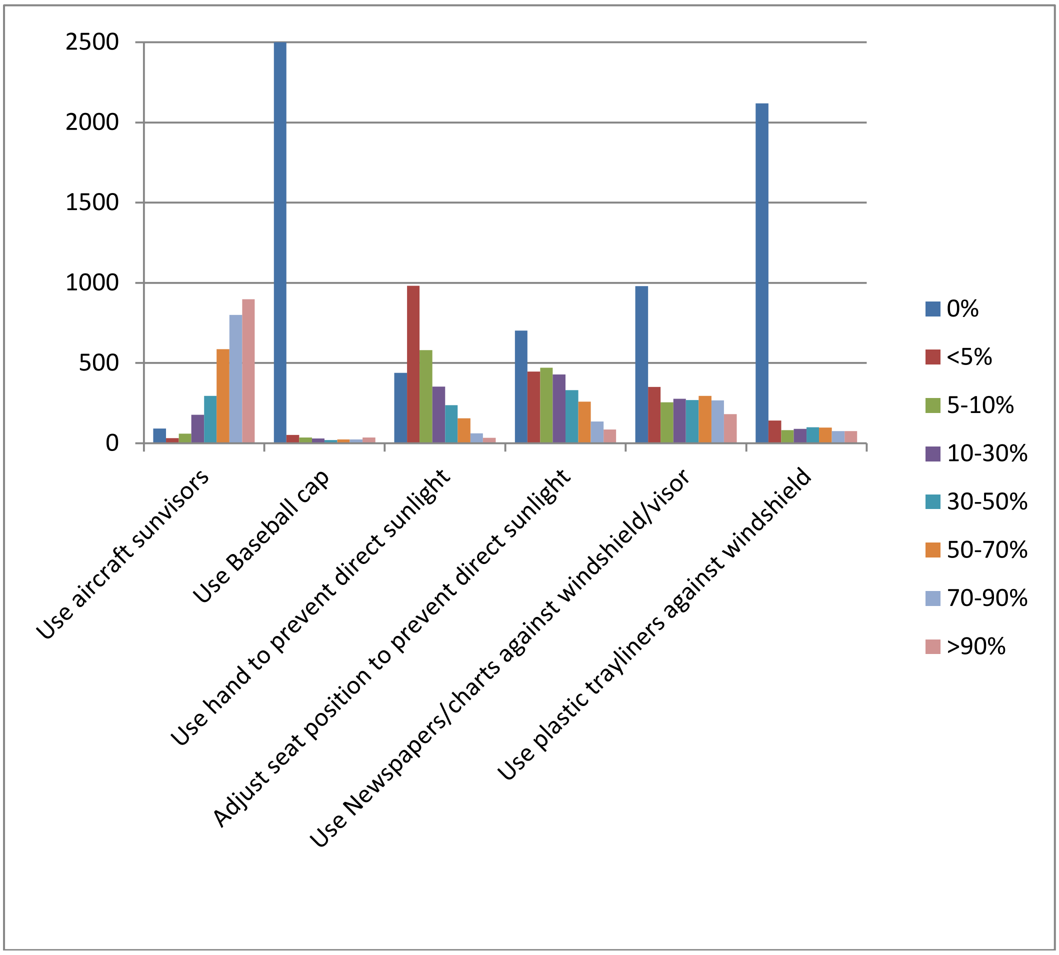

Figure 4-l Prevalence of use of other sun blocking strategies during flight.

There was no significant difference between spectacle and non-spectacle wearers in the use of visors, hand, newspaper, plastic sheet or other strategies (Mann Whitney U) however a baseball cap was significantly more likely to be used by spectacle wearers (Mann Whitney U, p=0.015). Additionally, seat adjustment was significantly more likely in spectacle wearers (Mann Whitney U, p=0.026).

Use of visor, hand or other strategies showed no significant difference between LH and SH pilots (Mann Whitney U). The use of a baseball cap, seat adjustment, newspapers and plastic sheet were all significantly higher in LH than SH pilots (Mann Whitney U, p<0.001 in each category).

Comparing LH, SH and HOS pilots, a significant difference was found in all strategies except ‘other’. The use of aircraft visors (Kruskal-Wallis, p<0.001), hand to block sun (Kruskal-Wallis, p=0.007), seat adjustment (Kruskal-Wallis, p<0.001), newspapers (Kruskal-Wallis, p<0.001) and plastic sheet (Kruskal-Wallis, p<0.001) were all significantly lower in HOS pilots. The use of a baseball cap was significantly higher (Kruskal-Wallis, $p<0.001$) amongst HOS pilots. There was no significant difference in the use of visors between ex-miltary and non ex-military pilots (pearson chi-square); however there was a significantly lower overall use of eye protection strategies other than sunglasses in ex-military pilots having allowed for age (ANCOVA, $F=12.1$, df 1, 2127, $p=0.001$).

A further 146 pilots declared other strategies used. These included the use of suction or stick on car side window blinds (n=39), aircraft checklists against windshield or attached to visor (n=34) and other items including paper, cardboard or envelopes against windshield or attached to visor. Fifteen pilots were flying in operations where a flying helmet with integrated visor was used. The following shows examples of the ingenuity of pilots to adapt the standard aircraft systems to give more effective sunlight protection:

480: *'slip an A5 sized duty free bag over the visor, I split in down one side to the mid point and then it slips beautifully over the standard Boeing clip on visor'*.

676: *'One or more sheets of paper can be stuck to the windshield by rubbing against the back of the paper until it stays in place. In my opinion the sun visors in the aircraft are almost totally useless. (777) the paper on the windshield does a great job in blocking direct sunlight'*.

734: *'clipboard clipped to sun visor, plastic checklist jammed into window frame, plastic checklist attached with rubber bands to visor'*.

1039: *'Cusions* (sic.) *from the aircraft jumpseat'*.

1041: *'Flight envelope from visor and trapped by standby compass housing Airbus'*.

1125: *'The soft HUD visor cover'*.

1207: '*I look more inside and use more autopilot (longer in time) to landing'*

1275: *'I carry 2 self expanding mesh sun shades (of the type used in cars) with centre suckers, usually doubled up, either stuck onto the windshield directly or onto the sun visor or between side sun visors to reduce light leakage in the gaps not covered by sun screens'*.

1823: *'I use a lightweight A3 size aluminised envelope slotted over the sunvisor to block the sun'*.

1840: '*foldable car type mesh stick-on shade (with Bart Simpson pic...)*'

1944: '*Napkin plus sun visor'*

2230: *'I use the anti static properties of the printer paper to block out direct sun. It sticks neatly to the window and can be moved around'.*

2397: *'have a roll of car window tint film that sticks with static electricity to the window'*.

There was a significant difference between LH, SH and HOS pilots in the number of strategies used with LH pilots being the highest users and HOS being the lowest users (Kruskal-Wallis, $p<0.001$).

4.9.8 Ocular health

Respondents were asked a series of eye health questions. 41 (1.4%) pilots had been told that they were developing or had been diagnosed with cataracts and 18 (0.6%) had undergone cataract surgery. 43 (1.5%) had been told that they were developing or had been diagnosed with macular degeneration. There was no significant correlation between any health question and the percentage of time that sunglasses were used during flight (Kruskal-Wallis). There was no significant difference in prevalence of UV related ocular pathology between ex-military and non ex-military pilots (Pearson chi-square).

There was no reported pathology from HOS pilots. Of the SH pilots, 0.8% reported as being diagnosed with cataract, 0.5% had undergone cataract surgery and 1.3% had been told that they were developing or had been diagnosed with macular degeneration. Within the LH pilot group, 2.1% reported as being diagnosed with cataract, 0.8% had undergone cataract surgery and 1.6% had been told that they were developing or had been diagnosed with macular degeneration. Although prevalence was higher in the LH group, Pearson chi-square analysis revealed that flying category did not have a statistically significant effect on cataract and intraocular lens implants declared, macular degeneration declared or overall pathology declared.

Independent T-Test analysis revealed that those declaring ocular pathology were significantly older for cataract ($t=7.8$, df 2892, $p<0.001$), cataract surgery ($t=3.2$, df 2892, $p=0.001$) and macular degeneration ($t=4.0$, df 2892, $p<0.001$). However, ANCOVA analysis showed no significant relationship between flight time logged and cataract ($F=0.01$, df 1, 2891, $p=0.93$), flight time logged and macular degeneration ($F=0.05$, df 1, 2891, $p=0.82$) or flight time logged and intraocular lens implant ($F=0.33$, df 1, 2891, $p=0.57$) once allowing for age.

A total of 890 (30.5%) respondents were aware of the role of diet in the maintenance of eye health. When questioned, 1763 (60.4%) pilots did not take regular vitamins or supplements, 1092 (37.4%) took regular vitamins or supplements for general health and not specifically for eye health reasons. 54 (1.9%) took regular vitamins or supplements for both general health and eye health concerns and 8 (0.3%) took regular vitamins or supplements specifically and solely due to eye health concerns.

The group of pilots taking supplements for general health purposes and eye health concerns had a significantly higher level of reported discomfort (Kruskal-Wallis, $p<0.001$) and disability (Kruskal-Wallis, $p=0.001$) glare. This group was also significantly younger (mean 1.5yrs lower) than the group taking no supplements (one-way ANOVA, $F=6.6$, df 3, $p<0.001$). Pilots taking regular vitamins or supplements specifically and solely due to eye health concerns had significantly lower reported disability glare (Kruskal-Wallis, $p=0.001$). Although this small group was also younger (mean 3.2yrs lower) than the group taking no supplements, the difference in mean age was not statistically significant (one-way ANOVA).

4.9.9 Further comments

Respondents were able to add free text comments to elaborate or comment on a number of their responses. Additionally, a general comments box for any other remarks was placed at the end of the questionnaire. A total of 731 comment boxes were assessed, coded and analysed. A summary is shown in Table 4-g.

The most prevalent theme from the free text comments box was that it was felt there was inadequate solar protection, particularly visors, fitted to aircraft. A total of 163 respondents commented, a sample of which are given below:

275: *'The general standard of sunshield provision on the Boeing 757/767 is a joke. The visors are often loose and cannot be positioned correctly... clearly designed by the most junior guy in Boeings design department...as an afterthought'.*

533: *'On my aircraft, the 747-400, the sun visor protections are woefully inadequate for the front windows. I spend hundreds of hours flying whilst looking at a low sun each year. I finish these flights with sore and tired eyes which concerns me as I then have to dive* (sic.) *a car home'.*

539: *'I find the aircraft sun visors to be poor and usually use the aircraft checklists to block out the sun, despite being against company policy'.*

728: *'. ..I have never yet flown a type of aircraft with adequate sun visors...'*

901: *'Aircraft sun visors are generally poor quality and difficult to adjust to exactly the right position as sometimes two are required in the same place to adequately darken the sun'.*

919: *'It is scarcely believe able* (sic.) *to me just how poor the sunshades are in both Airbus and Boeing aeroplanes (I have thousands of hours on both). No matter where you put whatever shade is provided, the sun always seems to peep round the side or through some chink in the screen. You can exclude light from a hotel bedroom but not, it seems from an aeroplane cockpit'.*

1196: *'Aircraft protection is totally inadequate and ineffective. We shouldn't be using sunglasses or visors when the aircraft should have fitted blackout blinds. I am concerned about this'.*

1379: *'Built in sun visors very poor design and tend to move from adjusted position; sometimes broken or missing, but generally ineffective'.*

2737: *'PLEASE get aircraft manufacturers to build suitable roller-blind type eye shields near the windows'.*

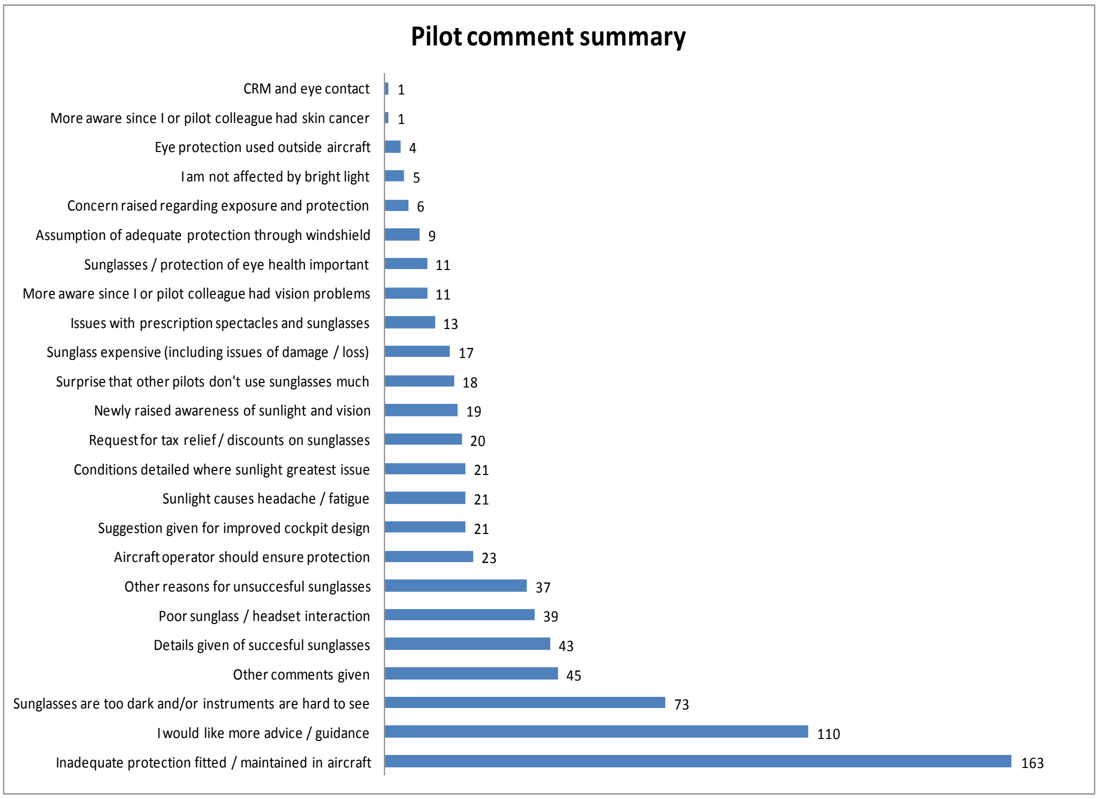

Table 4-g Summary of coding completed on free text boxes covering other comments made by respondents.

Significantly more negative comments were received regarding Boeing visors (65 negative, 5 positive) compared to Airbus (16 negative, 10 positive) (Pearson chi-square, X^2=14.1, df 1, p<0.001). Although more negative comments were received regarding the brightness of Airbus instrument displays (19 negative, 1 positive for Airbus, 3 negative, no positive for Boeing), Pearson chi-square analysis showed no significant difference between comments on Airbus and Boeing instrument displays.

A total of 54 comments were received regarding the perceived importance of using sunglasses during flight or details of successful sunglasses used:
157: *'It is a must. You only have one pair of eyes and they are essential for the job so look after them!'*
508: *'It is vitally important to protect the eyes at high altitude where there are high UV levels. It is worth investing in an expensive pair of sunglasses as you cannot replace your eyes!'*
1198: '*Couldn't live without my sunglasses - levels of glare do tend to be very high in flight deck, even when cloudy (I fly Boeing 737)'*
1122: '*My sunglasses are very important to me and if I forget to take them with me (usually because it's been sunny at home and they are still in the car) I find it to be a more difficult day at work as I am regularly irritated by the sunlight in my face'.*

In contrast, there were 162 comments highlighting the barriers to successful sunglass use including comfort, cost and issues with using corrective spectacles:
2118: *'For helicopter work, especially offshore, the best all round protection is afforded by wearing a helmet with attached sun visor. Generally they do not distort light at their edges and do not interfere with your periphery vision. Impact protection (birds, FOD* [foreign object debris]*) is a very important aspect of eye health that the industry mostly ignores. When I am supervising a rotors turning refuel on an offshore installation, with a 50kt wind blowing, with heavy rain and hail, your eyes are very vulnerable. Yet, we are NOT provided with ANY eye protection whatsoever. We are explicitly forbidden from wearing helmets'*.
2738: *'I bought aviators because, well, they're aviators and supposedly designed for flying. In reality the let in sun around the edges and probably the best type of sunglasses for protection are wrap around. However, as I spent a lot of money on getting aviator with prescription lenses (I also need corrective lenses while flying), I am unlikely to change until my prescription changes'*.

The most commonly reported barrier to sunglass use was that it made the instruments too dark to visualise clearly (n=73):

417: *'I would run out and buy new sunglasses tomorrow if I could find a tint and gradient that works with Airbus instruments, unfortunately it doesn't seem to be available'.*

979: *'One of the main reasons for not wearing sunglasses is the problem of not being able to adequately read EFIS displays with sunglasses on. Even with the screen brightness on MAX they are still too dim, so I just accept some discomfort caused by bright sunlight'.*

2477: *'In the cockpit I will wear my RayBan wrap-arounds proud of my face (held by the ear cups of my own Bose headset) to obscure sunlight while allowing my eyes unhindered view, below the coaming, of the instruments'*.

2554: *'Balancing being able to comfortably look out in sunlight and look in at the instruments in a dark cockpit is nigh on impossible to achieve'.*

A small group of respondents (n=9) reported an assumption was that the aircraft windshield provided adequate protection from any adverse health effects:

381: *'I assume the vast majority of UV does not pass the windscreen and it is not a health problem otherwise professional literature would encourage/oblige me to wear personal sunglasses for protection rather than just for convenience and comfort. If this is incorrect should they not be part of my safety equipment issue or at least be included in industrial health obligations?'*

907: *'As I can sit for a whole day in the sunshine in the cockpit and I do not get any tanning effect at all, I believe that the thick glass windows, like car windows, is opaque to ultraviolet rays'.*

1236: *'I have recently been diagnosed with a Rodent Ulcer below my left eye which has just been surgically removed. At present I am off with stitching and grafting of skin to cover this procedure. I always wear sun protection (Sun Cream & Glasses) except during flight as I thought there was adequate protection from ultra vilot* (sic.) *light. I am of dark skin and half Mediterranean background origin'.*

1840: *'Hard to imagine how an inch and a half of glass and acrylic isn't going to stop harmful UV and a millimetre of ray-bans is...'*

Conversely, six respondents expressed concern of the potential radiation dose that they may be subject to during flight. Concerns over both skin and eye exposure were raised:

1727*: 'Wear low factor sunblock on my face and try and wear prescription sunglasses when flying in daylight conditions, due to advice from my consultant dermatologist!'*
381: *'I used to wear sunglasses much more often. For some reason the brightness bothers me less even though when I stop to think about it I am concerned about UV effects on my eyes'.*

Additionally, 18 pilots expressed surprise and concern that other fellow pilots wore sunglasses infrequently:
196: *'I can't fly without them, it's far too bright in the cruise. I'm amazed how many pilots don't use them and are constantly struggling to see. I've even taken control of the aircraft for landing into sun, when it became apparent that the first officer was struggling to see! He had no sunglasses with him'*.
609: *'I am always amazed when people don't use sunglasses. They are VITAL'*.
728: *'Never ceases to amaze me how many of my colleagues don't use adequate eye protection from sunlight. Many just squint or rely on the always-poor aircraft sun visors...'*

Respondents showed engagement with the questionnaire as the second most prevalent theme within the free text boxes was for more guidance and advice to be published for pilots. A total of 110 such requests were received:
806: '*Exposure to UV light at work would be a concern if I thought I was, for example, at risk of developing skin cancer from UV passing through the windows'*
907: *'...If there is a risk to eye health from sunlight in the flight deck, I would appreciate knowing more about it'*.
2420: *'I am totally ignorant! News to me! I tried sunglasses but they made instruments (LCD) hard to read. Why? Polarised glasses? If I knew which sort to buy that worked I'd buy them! Ignorance again. Now you've got me concerned ??????'*

4.10 Questionnaire reliability

A measure of response survey reliability was made by repeating a question about the number of flying hours logged over the past year. One question was sited at the beginning of the questionnaire and was a free text box. The second question was near the end of the questionnaire and respondents were asked to provide their past year's total flight time logged in one of five categories. Cross tab analysis was conducted. 7 responses were ignored as the responder most likely missed or added a zero in error (for example stating 75 hours in the free text box and selecting the >700 hour category). 97.2% (n=2829) respondents gave equivalent responses to the two questions. 2.7% (n=78) were incorrect by one category band and 0.1% (n=3) were incorrect by two category bands. No error was greater than two category bands.

In analysing the data, it is recognised that some variables such as the presence of a spectacle requirement on a medical certificate, the use of sunglasses and the type of flying undertaken have been used on a number of occasions to test the statistical significance of their effect on other variables. It is also recognised that multiple testing of the same variable at $p<0.05$ will increase the probability of a false positive result if the results are considered simultaneously. Whilst care has been taken not to infer conclusions from a series of statistical tests, partly due to the large number of participants, a higher level of confidence (such as $p<0.001$) is afforded in a large number of the statistical tests conducted. Additionally, it should also be acknowledged that the questions to be addressed at analysis were planned at the time of the design of the questionnaire and additional analysis has been conducted only where further exploration of findings was warranted.

4.11 Questionnaire discussion

4.11.1 Participant demographics

It can be seen that the age range of the participants follows a normal distribution curve (Figure 4-b). Analysis of the age of respondents from the questionnaire compared to the total current UK professional licence holders from the audit data (described in section 4.13) is shown in Table 4-h.

	Questionnaire	**Audit**
N=	2917	22033
Mean age	42.57	40.12
Median age	43	40
Skewness	0.018	0.017
Kurtosis	-0.082	-0.078

Table 4-h Age demographic summary of questionnaire and audit populations.

While the skewness and kurtosis of the distribution remain similar, there was a significant difference in mean age between the two groups (independent t-test $t=10.88$, df 1, $p<0.001$). It should however be noted that the audit was carried out in April 2011 and the questionnaire was completed between December 2012 to March 2013. This may account, in part, for a younger mean age within the audit. Other reasons for this age disparity are discussed in section 4.15.

There are some variations from the normal curve from year to year (for example comparing pilots of age 38 to those age 39). Recruitment within the airline industry is subject to variation over time. Air travel is affected by the world economy and events such as the 9/11 terrorist attacks and airlines will recruit and employ pilots according to demand however overall, air travel is increasingly popular. This offers an explanation as to the drop in numbers of older pilots. However, there are also some pilots who may be found medically unfit before reaching the upper 65 year age limit for airline flying and some pilots may choose to leave airline flying before the age of 65. However, it is most likely that the lower numbers of older pilots reflect the fact that the industry was considerably smaller at the stage when they embarked on their training. The vast majority of professional pilots will have completed their training by the age of 30. If in the future, the size of the aviation industry remains static, the age demographic would be expected to change to become more even across the age range with the exception of each extremes of age. Participants questioned showed a good level of professional flying experience with 91.6% having accrued over 2,500 flying hours over a range of flight operations.

There is an expected rise in the requirement for the use of spectacles with age. The onset of presbyopia (Charman, 1989) and shift towards hypermetropia (Bennett, 2007) can cause a reduction in the level of unaided vision. There is also a slightly higher proportion of spectacle wearers within a younger age group (from around age 26-34). This effect may be in part due to a gradual relaxation to the myopia refraction limits (section 1.6) for initial medical certification resulting in more spectacle wearing applicants being eligible for certification. It also may be due to an increase in prevalence of myopia in the general population (Gilmartin, 2004; Vitale et al, 2009).

The overall prevalence of pilots using contact lenses during flight was 12.17%. This compares with 3.1% found amongst US civilian pilots from 1997 (Nakagawara et al, 2002). This study also found a significant increase in contact lens use among pilots from the 1960s to 1997. Due to the continued expansion of the contact lens industry, improvements in lens technology and range of lenses available, it would be expected that current prevalence of contact lens use in US pilots would now be significantly higher. It is estimated that in the general UK population age 15-65 years, the prevalence of contact lens use in those requiring optical correction is 18.1% (Personal communication D.Ruston 14/04/14) compared with 26.6% found in the study. This higher prevalence in contact lens use in the study group is surprising as it would be expected that prolonged contact lens use in the low humidity cabin environment would cause discomfort in some wearers. The higher contact lens use in the study group may be due to pilots being of a higher socio-economic group than the overall UK population and having more disposable income but may also be influenced by a pilot preference to be spectacle free when undertaking the aviation visual task. There is likely to be a number of factors influencing this decision, however the ease of using one pair of non prescription sunglasses when needed is likely to be a consideration. It can be seen that contact lens wearers use sunglasses more than spectacle wearers (Mann Whitney U, $p<0.001$).

4.11.2 Sunglasses

There is a remarkably uniform distribution of responses concerning the extent of sunglass use within professional pilots. It may seem initially surprising that nearly 25% of those questioned never used sunglasses or used them for less than 10% of the total flight time. It is clear that those pilots requiring optical correction are far less likely to use prescription sunglasses. This is due to a number of confounding factors including having to change glasses during flight and the cost of glasses. Normal age related ocular changes including lens and other media changes, increase in scatter and fluorescence of lens and cornea, reduced dark adaptation and glare recovery are all likely to increase glare sensitivity with age yet the older spectacle wearing pilot is less likely to use sunglasses. The most common reason for reduction in sunglass use with time is due to the onset of requiring corrective spectacles. It is interesting to see that younger pilots rate their sunglass performance higher. This could be due to the normal ageing ocular changes in older pilots impacting on visual performance in ways that are not fully ameliorated by sunglasses.

It is seen that the use of aviator style sunglasses is significantly higher in helicopter pilots while pilots operating airline jet aircraft are more likely to be using wrap around style sunglasses. These are likely to offer superior protection from peripheral radiation and the PLF effect (section 2.4). The long haul pilot in particular may be subject to long periods of flight with the sun in a similar relative position within their field of view. This also offers an explanation for the long haul pilot being more likely to have 2 pairs of sunglasses and the primary set to be a fixed tint. The helicopter environment during flight is noisier than a typical airline jet aircraft and therefore, helicopter pilots generally have to use heavier headsets with close cup fitting over the ears to minimize exposure to aircraft noise. The sides of a spectacle frame have the potential to push the headset cups away from the ears and decrease the effectiveness of the headset. An aviator frame is more likely to have a more compatible thin side for use by the helicopter pilot.

The results show that a major factor in the comfort of sunglasses, and as a consequence, the amount that they are used is the compatibility with the headsets. All pilots need to use headsets, not only to reduce ambient noise if required, but also to communicate with air traffic control and the other pilot(s). Not only were symptoms of discomfort reported around the ears independently by 39 participants, three pilots declared comfort as the reason for carrying a second pair of sunglasses during flight and sunglass discomfort was reported by 89 non-sunglass wearing participants as their reason for not using sunglasses. This was the fourth most prevalent reason and the proportion was much higher among those not requiring optical correction. This finding concurs with the results of the interviews in section 4.5.2. It is likely that those pilots who require a prescription are more adapted to wearing frames on a full time basis. They are also more likely to have had their glasses professionally adjusted for optimum fit (although 63.8% of sunglass users questioned had never had a fitting) than those pilots who have purchased non-prescription sunglasses from a retail outlet.

The Luxottica group manufactures a number of sunglass brands including RayBan and Oakley and represent the highest sales value percentage for sunglasses sold at UK retail outlets (67.6% compared to the second highest, Maui Jim at 8.4%) (Gfk, 2013). This was matched with the highest prevalence amongst sunglasses users in the questionnaire, with 54.1% using a Luxottica group sunglass product. Serengeti brand sunglasses were the next most popular in the questionnaire which did not feature in the top four highest sales value percentage (Gfk, 2013). It is therefore likely that pilot sunglass selection is not driven purely by product availability, but also other factors such as colleague or aviation medical recommendation and pilot targeted advertising.

Spectacle wearers may have consulted CAA guidance material regarding the use of contact lenses or criteria for spectacle frame choice. It may be therefore unsurprising that they are more likely than their non-spectacle wearing counterparts, to have consulted CAA guidance with regard to sunglasses. A higher proportion of younger pilots stating that they consulted guidance material could be due to having had more recent contact with the CAA Medical Department (at their initial Class 1 medical) as guidance material published on the CAA website has been published only within the past 10 years. Additionally, younger pilots are more likely to have required spectacles since their first medical certificate issue and thus consulted CAA guidance for this reason. Overall, the use of guidance material remains low at 10.7%. Before promoting any CAA guidance to pilots, it should reflect best practice and should be evidence-based.

The majority (86.8%) of the colour of sunglass tints described were grey, brown or green. These are unlikely to cause significant changes to perception of colour however it is recognised that perceived tint colour may not correlate well to the sunglass lens transmittance properties. For example, those describing a silver tint may have had a neutral grey tint and a mirrored reflective coating on the front surface of the lens. Additionally, some tints described as green or purple may have multi anti-reflection coating on the lens and those describing their sunglasses as blue or black may have a dark (higher absorption) neutral grey tint.

A number of pilots reported difficulty with the aircraft instruments appearing too dark when wearing sunglasses (73 reported independently and 58 non sunglass wearing pilots gave this as their reason for not using sunglasses). The obvious solution to counter this would be for the pilot to use a graduated tint which is darker at the top and lighter at the bottom of the lens. However, only 11.1% of sunglass wearing pilots had this type of tint with the majority having a fixed, equal density tint (71.6%). This disparity is surprising and could be due to a number of causes. Graduated tints in non-prescription sunglasses may be less prevalent or be under-reported by participants if the degree of graduation is subtle. It may also be that graduated tints are not used as they are perceived as offering a lower level of solar protection compared to an equal density tint. Another reason may be that graduated tints are less commonly available in the showroom frames that are typically found in sunglass outlets or magazines.

Overall, the majority of pilots questioned (70.4%) rated their sunglass as ‘good’ or ‘excellent’, although this did not include the pilots who never used sunglasses and who would have more likely had a poor previous experience. This positive rating is in spite of the low proportion (1.7%) using aviation specific sunglasses. This may be due to a low awareness that these sunglasses are available, the perception of a greater expense to purchase, scepticism about the claimed benefits, or that pilots perceived sunglass comfort is good with their current sunglasses. In addition to being more likely to have had their sunglasses fitted, corrective spectacle wearers also have significantly newer sunglasses than non-spectacle wearers which may explain the marginal but statistically significantly higher rating given by spectacle wearers.

Frame and tint comfort and UV protection were rated the most important factors in sunglass selection. The brand or label of sunglasses was considered least important and significantly more so amongst spectacle wearers who are likely to have reduced choice of sunglasses if requiring prescription. This reduced choice in spectacle wearers’ sunglasses would also offer an explanation for the lower importance ratings for frame style, frame comfort and UV protection described by this group.

Eight pilots independently reported that bright light environment caused them to sneeze. This is known as the photic sneeze reflex and is uncontrollable sneezing in response to a number of stimuli including bright lights and has been reported as affecting 18-35% of the population (Breitenbach et al, 1993). It is speculated that it is triggered by a change in overall light intensity and consideration should be given to the potential for pilot temporary incapacitation, particularly in the critical stages of flight. The reporting rate in this study is low, however it may have been higher had a question been specifically designed to establish prevalence within the pilot population. If this phenomenon is as common as reported, questioning and guidance on solar protection and sneeze avoidance could be given to susceptible pilots at their medical revalidation examination.

4.11.3 The flight deck environment

It is clear that bright sunlight conditions can be problematic in the flight deck. Bright light is the major cue for pilots to use sunglasses. Wide body commercial jet aircraft generally have front windshield and side windshield sun protection systems as described in section 1.5.7. Front visors can cover only a proportion of the total windscreen area but can on some aircraft, be positioned to be closer to the eye position by securing the visor at a point on the rail nearer the side window, thus increasing the area of visual field covered by the visor (Figure 4-m).

Figure 4-m Use of visors on a Boeing 757.

The results show that, although used commonly, these standard visors and blinds do not offer adequate comfort protection to the pilot throughout normal operations. A large number of negative comments were received regarding the visors and many pilots resort to using other means to manage the sunlight levels on occasions. In these situations, sunglasses may not attenuate the light levels sufficiently.
The range of other practices declared shows how pilots often use whatever is to hand within the cockpit to block glare from direct sunlight. A number of pilots have anticipated the potential in-flight issues of sunlight and ensure that they carry some

form of glare protection in their flight bag, such as a stick on car window blind marketed for glare protection for children. It is interesting to note that there is no significant difference in the use of strategies between spectacle wears and non-spectacle wearers with the exception of using sunglasses (lower among spectacle wearers) and using a baseball cap (higher among spectacle wearers). It would seem that with the additional barriers to sunglass use by spectacle wearers result in the use of a peak cap being a more practical option for this group. It is also of interest that ex-military pilots are lower users of eye protection strategies excluding sunglasses. This may be due to differences in initial pilot training and the availability of sun protection systems in military aircraft but also apparent is a lower use of non-standard sun protection practices by ex-military pilots.

The highest users of sunlight protection strategies are the long haul airline transport group. This is likely to be due to a greater proportion of the flight time spent at cruise, where the aircraft is likely to be operating in controlled airways, on auto-pilot and on a similar heading for potentially many hours at a time and where the requirement for spotting other traffic is reduced. The lowest users of the three most prevalent flying categories were the helicopter off-shore pilots. This would be expected for these operations which are lower altitude, short duration with more frequent changes of heading and a greater safety requirement for look out and spotting other traffic. It is also logical that the use of a peaked baseball cap is higher in this group as the windshield blocking strategies used by airline jet pilots are not appropriate.

The results show that although there was a wide variation between pilots in the use of sunglasses, there was no significant difference between the three most prevalent flying categories. There are a number of possible explanations for this. It is possible that sunlight conditions are such that similar illuminance levels are present for the low altitude helicopter flying and high altitude airline flying. It can be seen from the results that pilot sunglass use is strongly driven by prevailing conditions rather than by a particular stage of flight. There is likely to be a wide population variation in personal threshold of tolerance to bright light conditions due to a number of physiological and ocular factors including degree of ocular pigmentation, facial anatomy (e.g., prominent eyebrows, deep-set eyes), age, pupil size and presence of ocular media opacities. The wide spread of sunglass use across the main flying groups use supports this.

It might be expected that high altitude flight operations would result in higher levels of irradiance than lower altitude flights such as helicopter flights. However, the level of standard solar protection within helicopters is generally less than wide body jet aircraft and may consist of front visors only, a fixed tinted strip at the top of the windshield or no solar protection offered. Additionally, there would be greater flight safety implications for making adaptations during flight to block sunlight to the helicopter pilots' eyes. This lower level of aircraft solar protection may result in a lower personal threshold for the pilot to use sunglasses. If sunlight conditions are less extreme for helicopter pilots, their sunglass use may be equivalent to that of pilots operating at high altitude. Small private and business jet aircraft are a category of aircraft which have, in some cases, a similar level of standard sunlight protection to helicopters but which usually operate at higher altitude. Although, there were low numbers of business jet pilot participants (n=21), the group did use sunglasses significantly more than rest of the population surveyed (Mann-Whitney U, p=0.002). No difference was seen in the use of other eye protection strategies by business jet pilots compared to other pilots.

4.11.4 Eye health

There was no radiation exposure related ocular pathology reported by HOS pilots, however the group size was small compared to LH and SH pilots and it should not be concluded that SH and LH pilots are at an increased risk. The results show an expected correlation with age but not with flying experience once age is accounted for. The results show that 2% of the pilots questioned had cataracts or had undergone cataract surgery compared to 0.25% from the CAA medical record audit (n=22,033). Similarly, 1.5% of the pilots questioned had been diagnosed with macular degeneration compared to 0.05% from the CAA medical record audit. The relative under-reporting in the CAA medical records system may reflect a more open response from an anonymous questionnaire compared to a face to face medical examination and may elicit a positive response for early changes which may not be reported at a medical. It is also feasible that cases of cataracts and macular degeneration may be recorded on the pilot's medical record but not have been input under a specific read code which was used to conduct the audit.

A small proportion of the study population questioned took dietary supplements solely due or due in part to eye health concerns. It has been reported that the use of dietary supplementation of carotenoids meso-zeaxanthin, lutein and zeaxanthin can increase the macula pigment optical density (Connolly et al, 2010; Connolly et al, 2011). A high macula pigment optical density has, in turn, been reported to improve visual performance including resistance to glare symptoms (Nolan et al, 2011). In this study, it has not possible to assess the effect, if any, in reduction of glare symptoms as the groups are not age-matched and it is possible that people who are more prone to glare may be more likely to take dietary supplements.

There have been a number of studies reporting a poor understanding within the general public of the hazards of UV exposure to ocular health (Citek et al, 2011). This, together with the assumption made by some pilots that the aircraft windshield offers adequate protection (in turn, possibly due to the lack of skin effects noticed by the pilot) may offer some explanation as to the large number of pilots using sunglasses very little or not at all. Additionally, the most common reason for a pilot to increase their sunglass use is through awareness of potential impact to eye health; however this would be done without evidence-based data of an increased risk of ocular damage within the pilot population.

4.12 Audit introduction

The CAA Medical Department holds an electronic database of all class 1 (professional) and class 2 (recreational) medical certificate holders. An applicant may gain a medical certificate by attending the AeroMedical Centre or a local Aviation Medical Examiner, as appropriate. However, there are many medical certificate holders who do not have a valid licence. Here, the individual has not completed their flight training course and passed the appropriate examinations and skills test in order to be issued their licence. Equally, a pilot may hold a current licence (which may be valid for a number of years) but not hold a valid medical certificate. This may be because they have recently retired from professional flying or have the medical condition which, at the time of the audit, precluded medical certification.

The pilot’s medical record shows whether the individual is required to wear spectacles (or contact lenses) during flight and to carry an additional similarly correcting pair of glasses. This is known as a VDL limitation (wear corrective lenses and carry a spare set of spectacles). A presbyopic pilot with good distance vision will be required to have available a pair of reading glasses. This is known as a VNL limitation.

The CAA medical record database also has a Read code system. This is to allow specific medical conditions or findings to be documented on the pilot's medical record. A database search of the specific code would reveal all pilots with that condition.

4.13 Audit method

During April 2011, a search was conducted of the CAA medical records to identify all current class 1 medical certificate holders who also held a current commercial licence. Within this group further searches were conducted to establish the total number of VDL and VNL limitations present. Read codes were identified which corresponded to known UV related pathology. These were cataract, history of cataract extraction, keratopathy, pterygium, melanoma and macular degeneration. Where pathology had been recorded, the individual record was checked to assess whether another cause had been identified (for example a cataract caused by traumatic injury to the eye). As a number of Read codes are available for conditions such as cataracts, cases were cross-referenced so that no one individual was counted twice for the same pathology.

4.14 Audit results

As of the time of the audit, there were 22,033 current UK class 1 licence holders on the UK CAA database. 4,267 (19.37%) had a VDL limitation and 1131 (5.13%) had a VNL limitation on their medical certificate.

54 pilots (0.25%) had a history of cataract recorded (2 pilots with traumatic cataracts were excluded), 5 (0.02%) had macular degeneration, 11 (0.05%) had pterygium and 12 (0.05%) had melanoma (1 of which was ocular). No keratopathies were recorded.

4.15 Audit discussion

There is a difference in the presence of a VDL requirement between the audit population (19.4%) and the questionnaire respondents (45.7%). It is uncertain why such a discrepancy exists however it may be due in part, to the difference in mean age between the groups and the increasing prevalence of a spectacle requirement with age. It is also possible that some participants with good distance vision and a

VNL requirement for reading glasses responded positively to the survey question regarding the presence of a VDL limitation on the medical certificate. However, according to audit results, this group constitutes a relatively small proportion (5.1%) of the pilot population.

The number of licence holders found in the audit does not relate to the number of pilots employed by UK airlines (10,159 in 2013) (Civil Aviation Authority, 2013). Several factors are likely to account for this discrepancy. These include a population of UK commercial licence holders seeking employment by UK airlines, UK commercial licence holders working for non-UK airlines and pilots who have carried out other types of commercial flying including instructing, business jet and helicopter pilots.

It is therefore not known if the spectacle and pathology prevalence stated above is representative of the UK professional airline pilot population. It is likely that those seeking employment may be of a younger mean age than those currently employed. Additionally, those excluded from the audit due to not having a valid medical certificate (due to retirement or medical unfitness) are likely to be of an older age. These factors combined may produce a younger mean age within the audit group however there are also some pilots (retired from airline work) who continue to maintain a commercial licence.

4.16 Summary

The results from phase 1 reveal that bright sunlight conditions occur in flight which can be distracting, uncomfortable and less commonly debilitating for the pilot. Pilots are critical of standard aircraft protection systems and commonly employ other strategies to manage bright light. Although one strategy available to the pilot is to wear sunglasses, there is a surprisingly wide variation in use between pilots. The most common reason for not using sunglasses is due to the requirement to wear corrective spectacles. A wide variety of sunglasses are used by pilots although aviator styles are used more commonly be helicopter pilots and wrap-around styles are used more frequently by long haul pilots. There is a low take up of sunglasses specifically marketed for pilots.

Although there was a low prevalence of non-ionising radiation related ocular pathology reported in both study group and in audit results, professional pilots appear to show an interest in this topic with a strong questionnaire response rate together with requests for more information and guidance.

5. Chapter 5 Spectrometer description, calibration and data handling

CHAPTER OVERVIEW

This chapter appraises methods for measuring spectral irradiance. This is followed by introduction and description of the equipment used for irradiance and transmission measurements for this research. The equipment reliability, calibration and limitations will be discussed together with detail of its positioning and the development of a measurement protocol for in flight data collection. The software used for the capture and spectral management of data will be described. Details of the nature and extent of the collaboration with Public Health England for this phase of the project will be given.

5.1 Introduction and appraisal of methods for phase 2

In order to assess pilot ocular exposure, field measurements are the most relevant means of data collection. Solar simulating lamps may not be truly representative of the solar spectrum (Parisi et al, 2004) and will not replicate actual irradiance levels.

Exposure radiation data can be collected using various methods. Film badge personal dosimeters have been described using various materials most commonly polysulphone (Davis et al, 1976, Diffey and Roscoe 1990), but also allyl diglycol carbonate (CR39) (Wong et al, 1992), nalidixic acid (Tate et al, 1980), 8-methoxypsoralen (Diffey & Davis, 1978), bacteriophage T7 (Ronto et al, 1992) and bacteriophage T1 (Furusawa et al, 1990). These dosimeters respond to UV and provide a measure of cumulative dose over a period of time.

Polysulphone has a high response in UVB which drops rapidly for wavelengths greater than 300nm and does not respond to wavelengths greater than 330-340nm and therefore cannot be employed for the measurement of UV exposures in an environment where wavelengths shorter than 330-340nm are not present (Parisi et al, 2004). Polysulphone response is independent of temperature during its exposure (Giess, 2003), however will saturate with higher UV exposures. These dosimeters give only an accumulative measure of UV dose with no spectral information of the irradiance and no measure of visible or blue light hazard. While being useful in the estimate of skin exposure where multiple films can be deployed on various anatomical locations, their use for ocular exposure is limited.

Other dosimeters such as personal electronic dosimeters (Tracerco, Thermo Scientific), quartz fibre (Ludlum Measurements Inc) and thermo-luminescent (Mirion Technologies) dosimeters are not sensitive to the non-ionising UV and visible part of the electromagnetic spectrum.

Radiometers measure the total amount of non-ionising electromagnetic energy within a set wavelength range, for example UV or IR. Spectrometers generally use the addition of an optical grating or prism in order to split the incoming energy by wavelength which is detected by multiple sensors. Some spectrometers use a scanning principle taking successive measurements across the spectrum as the wavelength of the beam is altered (ISO 12311, 2013). Therefore, a spectrometer will allow measurement of the wavelength range of interest with spectral information of the intensity of radiation at differing wavelengths. Indeed, spectrometers are often used to calibrate film personal dosimeters (Parisi et al, 2004).

Traditionally spectrometers have been bulky and less suited for deployment within the relatively confined space of an airline flight deck. Additionally, scanning instruments are less suited for measurements in fast changing irradiance conditions as may occur during flight. However, smaller high resolution spectrometers are more recently commercially available which make in flight irradiance measurement a feasible proposition.

Ocean Optics is one manufacturer of small form factor spectrometers. These are compact and portable and although not specifically designed for use in a cockpit environment, have been used in a number of applications including measurement of LED output (Ryu et al, 2006), colour measurement of live bird plumage (Quesada and Senar, 2006), remote measurements of volcano surveillance (Galle et al, 2003) and gathering spectral data on Mt Everest and Mars (SpaceRef, 2012). There are a number of spectrometers available sensitive over different ranges of the non-ionising electromagnetic spectrum. The spectrometer can be further customized by the manufacturer with the insertion of different optical gratings and bench options in order to target the wavelength range of interest.

The spectrometer requires input optics, such as a cosine corrected diffuser, in order to capture spectra from a wide field of view (Ocean Optics, no date a) and transmit radiation for irradiance measurements. Where a beam of incident radiation strikes the diffuser at an angle away from normal, a larger area of the sensor is affected than if incident radiation were perpendicular to the diffuser. As the radiant flux is constant but detected over a larger area, a false low signal will result. The level of signal decrease is proportional to the cosine of the angle from normal. Measurements through cosine corrected diffusers account for this and are therefore unaffected by the angle of incident radiation.

However, cosine responders have been reported to differ by more than 10% from the ideal cosine response and cause errors in the measurement of overall spectral irradiance (Seckmeyer and Bernhard, 1993). Diffuse radiation is less affected by cosine errors than direct radiation (Bais et al 1997) and it is reported that, for practical purposes, cosine error may not be important although can cause uncertainty of data (European Commission, 1995). The degree of uncertainty can be quantified by assessing the individual diffuser head's cosine response function.

Appropriate steps must be taken in order to ensure the accuracy of the spectroradiometer. Causes of inaccuracy of spectroradiometer measurements include wavelength accuracy, photometric accuracy, stray light, resolution, stability, instrument noise and changes in temperature.

Wong et al (1995) recommend that a spectroradiometer should have a resolution 1nm or better and a sensitivity of 0.1 uW/cm2 at 300nm for solar UV measurements. It has been recommended that for accurate UV measurement, a spectroradiometer should have a wavelength precision of +/-0.2nm and not more than +/-0.1nm from one part of spectrum to another (European Commission, 1995). The degree of error through inaccurate wavelength verification is strongly dependent on wavelength (Bais et al, 1997). Small wavelength errors introduce significant errors in irradiance in UVB range (Seckmeyer and Bernhard, 1999). Stray light can be reduced using a double monochromator spectrometer which uses two diffraction gratings. However, these units tend to be larger in size. Most spectroradiometers are sensitive to temperature (European Commission, 1995).

McKenzie et al (1993) recognised that careful procedures must be followed to ensure quality of data and recommended wavelength and irradiance calibration for each measurement session. A well maintained high quality spectroradiometer is not expected to vary more than 2% between spectral irradiance calibrations (Bais et al

1997). The calibration procedure and the quantification of accuracy of the spectrometer and associated optics is detailed in section 5.6.

5.2 Description of equipment

Spectral irradiance measurements were carried out using an Ocean Optics HR4000 miniature CCD array spectrometer. The HR4000 is a high-resolution model with 3,648 detector elements. An HC1 composite grating was installed which operates from 200 to 1050nm (Ocean Optics, no date d). To enhance UV sensitivity, the HR4000 has a UV CCD array upgrade installed. Electromagnetic radiation was collected through a CC-3-UV cosine corrected diffuser which collects radiation through 180 degrees (Ocean Optics, no date a), and is transmitted via a metal sleeved QP600-2-UV/BX 2 metre optic fibre cable.

The Spectrometer was connected via USB cable to an ASUS R2E palmtop computer (Windows Vista operating system) on which was installed two software packages to facilitate spectral data collection and storage. These were Ocean Optics Monitor, Automated Spectrometer Acquisition System (ASAS) V4.13 and Ocean Optics SpectraSuite software. ASAS was used for data collection during flight and for office measurements. The SpectraSuite software was used for transmittance measurement of sunglasses, aircraft windshields and translucent aircraft visors.

For in-flight and office measurements, an Ocean Optics INLINE-TTL-S optical shutter (Figure 5-a) was connected directly to the HR4000 by an RS232 cable. The shutter was controlled by ASAS through the single USB cable connecting the palmtop to the HR4000. Power to the shutter was supplied by a YSN-12680 12V DC battery.

In order to ensure sufficient battery power throughout the flight, the palmtop was connected to an XCell pro external battery which allowed around 8 hours of continuous operation of the palmtop and HR4000 (Figure 5-a). For long flights, a second XCell pro battery was available.

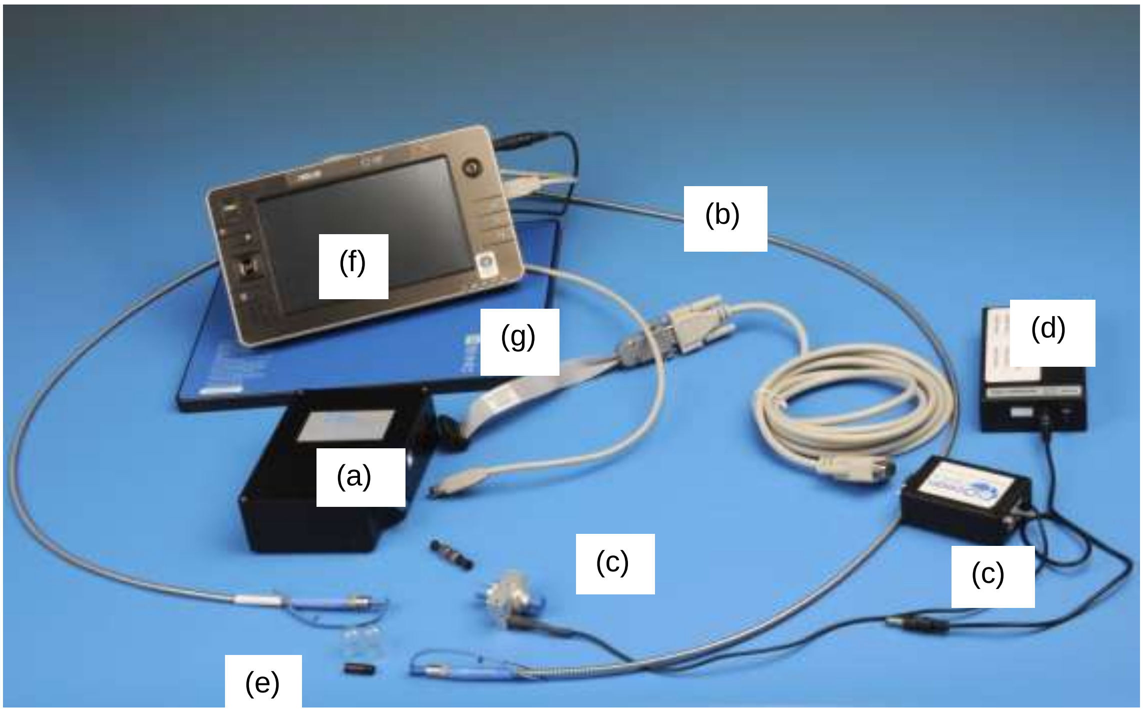

Figure 5-a Components of automated measurement equipment: (a) – HR4000 spectrometer, (b) – optical fibre, (c) – in-line TTL shutter with control box and power supply, (d) – shutter battery, (e) - CC-3-UV diffuser, (f) – palmtop computer, (g) – battery.

Two miniatureTR-74U*i* illuminance UV Recorders (T&D Corp, Japan) shown in Figure 5-b were used to record illuminance. One unit was at a fixed position next to the input optics of the HR4000 and was programmed using illuminance UV Recorder software V1.06 to capture illuminance data time-synchronised with spectral measurements. The second unit was used by the researcher to take a series of manual readings during flight (described in section 5.9).

Figure 5-b T and D TR-74UV*i* illuminance UV recorder.

5.3 HR4000 technical specifications

The HR4000 is a sealed unit. The casing measures 15cm x 10.5cm x 4.5cm. The weight of the HR4000 is 570g. The optical bench has no moving parts and all the components are fixed in place at the time of manufacture. The path of radiation within the unit is shown in Figure 5-c. Table 5-a lists internal components of the spectrometer.

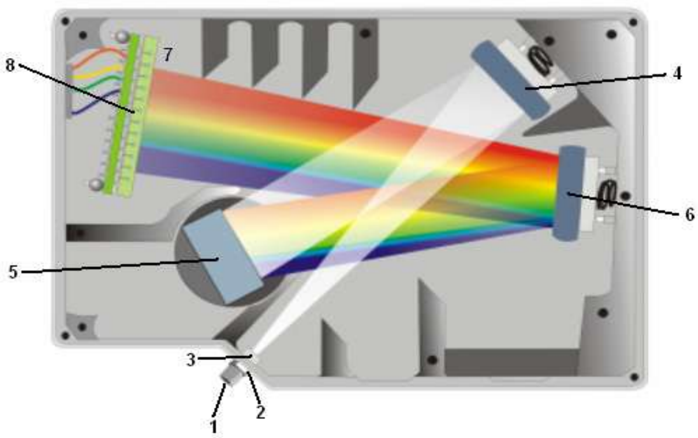

Figure 5-c Diagrammatic representation of the path of radiation within the HR4000 unit. 1 = SMA connector, 2 = Slit, 3 = Filter, 4 = Collimating mirror, 5 = Grating, 6 = Focusing mirror, 7 = Detector collection lens, 8 = CCD connector. Taken from Ocean Optics.

The HR4000 spectrometer has a 25-micron slit width which enables, accounting for the detector elements and grating type (HC1 200-1100nm), a resolution of 1.09nm full width half maximum (FWHM) across the spectra (Ocean Optics, no date e). A higher resolution is obtained at peak response (Figure 5-d). The wavelength step is the spectral range of the grating of the spectrometer divided by the number of detector elements. The average wavelength step across the spectrum is 0.247nm. The spectrometer can operate at up to 263 scans per second across the entire electromagnetic spectral range to which it is tuned (Ocean Optics, 2007).

Item	Name	Description
1	SMA Connector	Secures the input fiber to the spectrometer. Light from the input fiber enters the optical bench through this connector.
2	Slit	A dark piece of material containing a rectangular aperture, which is mounted directly behind the SMA Connector. The size of the aperture regulates the amount of light that enters the optical bench and controls spectral resolution. Only Ocean Optics technicians can change the Slit.
3	Filter	Restricts optical radiation to pre-determined wavelength regions. Light passes through the Filter before entering the optical bench. Both bandpass and longpass filters are available to restrict radiation to certain wavelength regions. Only Ocean Optics technicians can change the Filter.
4	Collimating Mirror	Focuses light entering the optical bench towards the Grating of the spectrometer. Light enters the spectrometer, passes through the SMA Connector, Slit, and Filter, and then reflects off the Collimating Mirror onto the Grating.
5	Grating	Diffracts light from the Collimating Mirror and directs the diffracted light onto the Focusing Mirror. Gratings are available in different groove densities, allowing you to specify wavelength coverage and resolution in the spectrometer. Only Ocean Optics technicians can change the Grating.
6	Focusing Mirror	Receives light reflected from the Grating and focuses the light onto the CCD Detector or L2 Detector Collection Lens (depending on the spectrometer configuration).
7	L2 Detector Collection Lens	An optional component that attaches to the CCD Detector. It focuses light from a tall slit onto the shorter CCD Detector elements. Only Ocean Optics technicians can add or remove the L2 Detection Collection Lens.
8	CCD Detector (UV or VIS)	Collects the light received from the Focusing Mirror or L2 Detector Collection Lens and converts the optical signal to a digital signal. Each pixel on the CCD Detector responds to the wavelength of light that strikes it, creating a digital response. The spectrometer then transmits the digital signal to the OOIBase32 application.

Table 5-a Details of the function of each component. Taken from Ocean Optics.

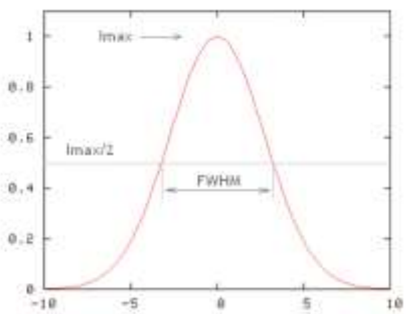

Figure 5-d Full width half maximum (FWHM). A peak sensitivity is present at each detector element. A range is present at a value of half of the peak sensitivity. This range is used to define spectrometer resolution.

The integration time is the period over which the sensor accumulates photons of incoming radiation. This is adjusted so that longer integration times are used in lower light levels and shorter integration times are required in bright environments. This enables meaningful data over a wide range of light levels. The number of scans accumulated by the detector prior to a spectrum being produced can be adjusted. An increase will improve the signal to noise ratio. The maximum integration time available is 10 seconds.

"Well depth" is specific to the CCD array spectrometer; the HR4000 used in this study has a well depth of 16,383 counts. A measurement containing more than 16,383 counts at any measured wavelength is therefore saturated and the unit is unable to capture the full signal strength. Additionally, where the signal is saturated, there is likely to be a charge leakage from the saturated pixel onto adjacent pixels causing a larger signal to these neighbouring pixels.

Using the SpectraSuite software, the 'boxcar width' can be changed. Here, each detector element is averaged with a specified number of adjacent elements. This can improve the signal to noise ratio and will smooth the spectral curve. However, there is a loss in spectral resolution if set too high (Ocean Optics, 2007).

5.4 Limitations of spectrometers

A number of factors may affect the performance of a spectrometer (ISO 12311, 2013; Lam, no date). The photometric accuracy relates to the accuracy of irradiance values (y axis). The wavelength accuracy is a measure of the wavelength reading of the spectrometer compared to known wavelength (x axis). Inaccuracies will affect the sensitivity of readings especially where peak or particular wavelengths of interest are studied. Wavelength accuracy may be affected through knocks or large thermal cycling to the unit. Photometric and wavelength accuracy are ensured through calibration against known light sources (described in section 5.6).

Spectrometer accuracy can be affected by stray light. Light of wavelengths outside the selected bandwidth wavelength are detected. It is caused by light scattering, higher order diffraction or instrument design (Lam, no date). Stray light can occur either around the wavelength of interest (near field) or where a visible photon is detected by a more sensitive UV detector (far field). Its effect can be tested at certain wavelengths with various cut off filters that have sharp cut off transmittance profiles (Agilent Technologies, 1997). However, the stray light can only be assessed at the wavelengths corresponding to the filters used. HR4000 data quotes stray light values of <0.05% at 600nm and <0.10% at 435nm. (Ocean Optics, 2008a). Stray light may be reduced where the spectrometer is calibrated using a similar reference standard to that against which measurements are taken.

Accuracy of a spectrometer is also affected by its resolution, stability (ensured with regular calibration checks), noise and baseline flatness. Noise can be caused by photons from a light source at low absorbance or from electronic components at high absorbance. Baseline flatness is the spectrometer's ability to compensate for variations in intensity of the source and variations in response sensitivity of the detector over the spectrum (Lam, no date). Noise and baseline flatness errors are reduced by taking a dark measurement immediately after a spectral reading. These data can then be subtracted from the spectral data.

5.5 Collaborative work with Public Health England (PHE)

The Centre for Radiation, Chemical and Environmental Hazards at PHE (formally the Health Protection Agency) was approached and a meeting set up to discuss the research project proposal. PHE have extensive experience in the collection of spectral data (Khazova and O'Hagan, 2008; Baczynska and Khazova, 2014; Price et al 2014) and have appropriate expertise to advise on valid measurement protocol and had on site facilities to calibrate equipment.

Following this meeting, PHE agreed to assist for the spectrometer parts of the project. A contract was drawn up and agreed by the legal departments of the CAA and PHE. The contract was for a two year period and the scope of the collaborative work comprised of:

1. Providing advice on spectral and broadband measurements protocol in cockpits.
2. Providing in-fibre shutter for Ocean Optics HR 4000 spectrometer for the duration of the project.
3. Providing calibration of CAA Ocean Optics HR 4000 spectrometer.
4. Providing automation and data processing software for Ocean Optics HR 4000 spectrometer.
5. Training CAA's researcher to operate automation and data processing software
6. Providing support with transmittance measurements of sunglasses.

Training on using the automation software and optical shutter was carried out at PHE on 13 March 2012. A further series of progress meetings were arranged throughout data collection and data analysis phases to discuss the various collaborative elements described above.

5.6 Reliability of spectrometer

The HR4000 was periodically calibrated using a 1kW Tungsten Halogen calibration lamp (BN 9101-548) and, for in flight measurements using the solar spectrum and a scanning double-grating monochromator D^3 180 (S/N 0116B-09-00) as a reference instrument. Wavelength accuracy was periodically assessed using a low pressure Hg penray lamp with known mercury position lines and additionally before and after each deployment using the mercury peaks from a standard fluorescent tube light.

The HR4000 showed increasing degrees of uncertainty of spectral measurements below 350nm without multi-region measurements. The instrument remained sensitive to 800nm. The effect of low signal strength was assessed and the HR4000 was accurate provided that the signal was at least 2 standard deviations above the mean background noise level. Angular response of the CC-3-UV diffuser showed a match to the ideal cosine response within 5% for incident angles +30° to -30° and was consistent with wavelength. Between 30° to 50°, the CC-3-UV was found to underestimate between 5-10%. For the assessment of ocular hazard, ICNIRP (2010) guidance was adopted which states that the detector field of view can be reduced and limited to +40° to -40°.

The sensitivity change of the HR4000 with temperature between 22°C and 35°C was within 2-3%, with respect to the sensitivity at 22°C. The capture of a dark signal after every spectral measurement countered the issue of increased background noise with increasing temperature.

The HR4000 was found to have good stability throughout all photometric and wavelength calibration checks carried out. There was no deviation seen beyond the range of instrument uncertainty. Throughout all flights, the HR4000 unit was placed in a shaded location in the cockpit, away from any heat generation from the palmtop or batteries. This maximised the board temperature stability and additionally controlled it to within the 22°C - 35°C optimum operating range.

The calibration procedure, assessment of accurate range and variation with temperature is described in further detail in appendix M.

5.7 Automated Spectrometer Acquisition System (ASAS)

ASAS has been designed for operation with Ocean Optics CCD array spectrometers when measurements are required to be repeated at specific time intervals under variable illumination conditions. The schedule (start, end and interval times) between measurements can be set within ASAS software so that measurements can be run autonomously. Captured data may be analysed within ASAS and the results are displayed in tabular and graphical formats.

ASAS program automatically determines the acquisition time of the current light conditions for the specified spectral range to reach a user-defined target count level. Between scheduled measurements, the equipment continuously takes acquisitions and estimates the integration time for next scheduled data collection. Within each scheduled acquisition, up to three spectral regions can be chosen to optimise signal-to-noise within a narrower spectral range than the full spectral capability of the instrument. The maximum count level measured by HR4000 in 200nm - 1100nm for solar spectrum is at approximately 530nm; the signal measured at 400nm is 20-30% of the maximum value and at 350nm, the signal is less than 10% of maximum value, whereas background is nearly constant across whole spectral range. If the full spectral range is measured in a single acquisition, data below 400 nm may suffer from low signal-to-noise.

Splitting the full instrumental spectral range into segments enables optimisation of the signal in each spectral region separately while allowing saturation outside the region of interest. Selected individual spectral regions can be then electronically “stitched” together using a further software package, the Spectral Stitching Program (SPP) to obtain the complete spectrum. Setting the spectral ranges of the three regions to partly overlap provides control measure.

For in-flight measurements, the following spectral regions were chosen: 280nm – 400nm, 380nm – 500nm and 280nm – 1100nm (the complete spectral region of the HR4000 spectrometer). Where saturation occurs outside the restricted spectral range, charge from saturated pixels may leak into adjacent pixels. This effect is especially critical in measurements of the short wavelength UV range where variations in signal level are high. To avoid saturation in the target spectral region and signal non-linearity near saturation level, the measurement spectral range was set wider than the spectral range of interest. Therefore, 280 – 450 nm acquisition boundaries were set for the 280 – 400 nm spectral region and the target count level was set at 15,000, which was approximately 90% of the maximum 16,383 counts.

The time interval between scheduled measurements can be set from a few seconds to 99 hours. The time interval must be greater than the actual time required to capture, read out and save light and background data. If a lower time interval is set, ASAS automatically calculates the minimum time interval based on the set maximum integration time and relays a warning to the user. The minimum time interval for three spectral regions acquisition based on the maximum integration time (10 sec) is three minutes. For in-flight measurements, a time interval of ten minutes was set.

Due to potential issues of rapidly changing light conditions during flight, the three spectral regions measurements were arranged consecutively and the order was selected to minimise the time between the start of the first spectral measurement and the final dark measurement. This could be achieved if the dark signal of the longest integration time was carried out last in a series. It was anticipated that the integration time required for the UV region would be an order of magnitude longer than that for the full range. Therefore, region R1 covered the full spectral region of 280nm – 1100nm, region R2 covered the spectral region of 380nm – 500nm and region R3 covered the spectral region of 280nm – 400nm.

The wavelength step for the HR4000 is 0.247nm. Raw data were collected from 195.8112nm to 1117.629nm. This constituted 3648 rows of data for each measurement. Data were saved as raw spectral data and, if selected, as spectral irradiance and effective spectral irradiance weighted with a specific action spectrum, providing that the instrument was calibrated for spectral irradiance and that background measurements were available. A calibration file could be uploaded to the ASAS software folder. Built-in spectral weighting could be chosen from ultraviolet hazard spectral weighting function S(λ) (ICNIRP, 2004), erythema spectral weighting function (CIE, 1998), blue light hazard spectral weighting function B(λ) (ICNIRP, 2013) and retinal thermal hazard spectral weighting function R(λ) (ICNIRP, 2013). For each measurement, the data file saved the raw signals for light and dark signals, the calibration, un-weighted and if spectral weighting was chosen, the effective irradiance. Results are displayed graphically and saved within the data file.

5.8 Spectral stitching

The data from the three spectral regions at each data collection point were assessed to determine whether stitching were required. Appendix N describes the methods, criteria and procedure used where spectral stitching was required.

5.9 Use of illuminance UV recorders

Due to the use of three region measurement, each with dark measurements and the software capability to automate data collection, it was decided to site the spectrometer at a fixed point in the cockpit. In order to evaluate ocular exposure, data would need to be collected at an equivalent point in space to the pilot's eye. Additionally, data capture would need to be fast and unobtrusive so as not to distract the pilot during flight. This would have to be conducted by the researcher from the jump seat (a third seat on the flight deck behind and usually between the two pilot seats). It was felt although the spectrometer cosine detector and fibre optic cable were small, each data measurement would be time consuming and subject to variability with inadvertent movement of the probe during or between region measurements.

Two identical T&D miniatureTR-74U*i* illuminance UV recorders were therefore additionally used for in-flight measurements. One was positioned in a fixed location together with the spectrometer and the researcher used the second meter to quickly capture a series of manual readings during flight. Ocular spectral irradiance levels could then be calculated by comparison of time matched data from the 2 illuminance UV meters and applying the degree of signal change between fixed and manual meters to the spectrometer data.

Manual readings were recorded every 10 minutes during spectrometer data collection except when measurement may have caused distraction to the pilots. Here, a measurement would be taken as close to the 10 minute interval as practically possible. Three readings were taken on each occasion. The first was with the sensor at the pilot eye level facing forward over the instrument cowling to simulate the pilot looking straight ahead through the front windshield. The second reading was from the same position in space at pilot eye level with the sensor angled downwards towards the primary flight instrument displays. The third reading taken was a maximum obtainable from the jump seat and was usually in the direction of the solar disc and potentially measured through either front or side windshields.

5.10 Calibration of illuminance UV recorders

Both illuminance meters were assessed using the same certified calibration lamp as used for the spectrometer irradiance calibration. Measurements were taken at the same distance from source as were taken for the HR4000. The 2 units agreed to within 0.2% and both were within 1% of the HR4000. The angular response of the TR-74U*i* units were similar and were found to be 6% at ±30° and 8% at ±40° from the ideal cosine response.

5.11 Spectrometer location in relation to pilot eye position

It is estimated that the position of the input optics of the spectrometer relative to the pilot eye position would be within 70cm for the pilot operating from that side of the aircraft. The shape of the spectra between these two locations could potentially be affected by a number of factors:

1) Reflective surfaces could potentially selectively increase particular regions of the spectra. The cockpit ergonomics are such that this is minimised by manufacturers by using dark matt surfaces.

2) Direct sunlight through the side window. If the transmission properties of the side window were different to those of the front windshield, it is

possible that the spectra reaching the eye could be composed of different components. However, the effect on ocular dose of a direct light source near 90 degrees to fixation is likely to be minimal.

3) Front visors. These also have the potential to influence the spectra reaching the ocular surface which may comprise a mixture of filtered spectra through front windshield and visor and front windshield alone. The spectral properties of measured visors are discussed in section 8.4.

Figure 5-e shows a series of spectral readings taken just behind the right windshield (RH) and at the pilot's left and right eye position positioned in the right seat looking ahead and towards instruments from the right seat of an aircraft at Exeter airport.

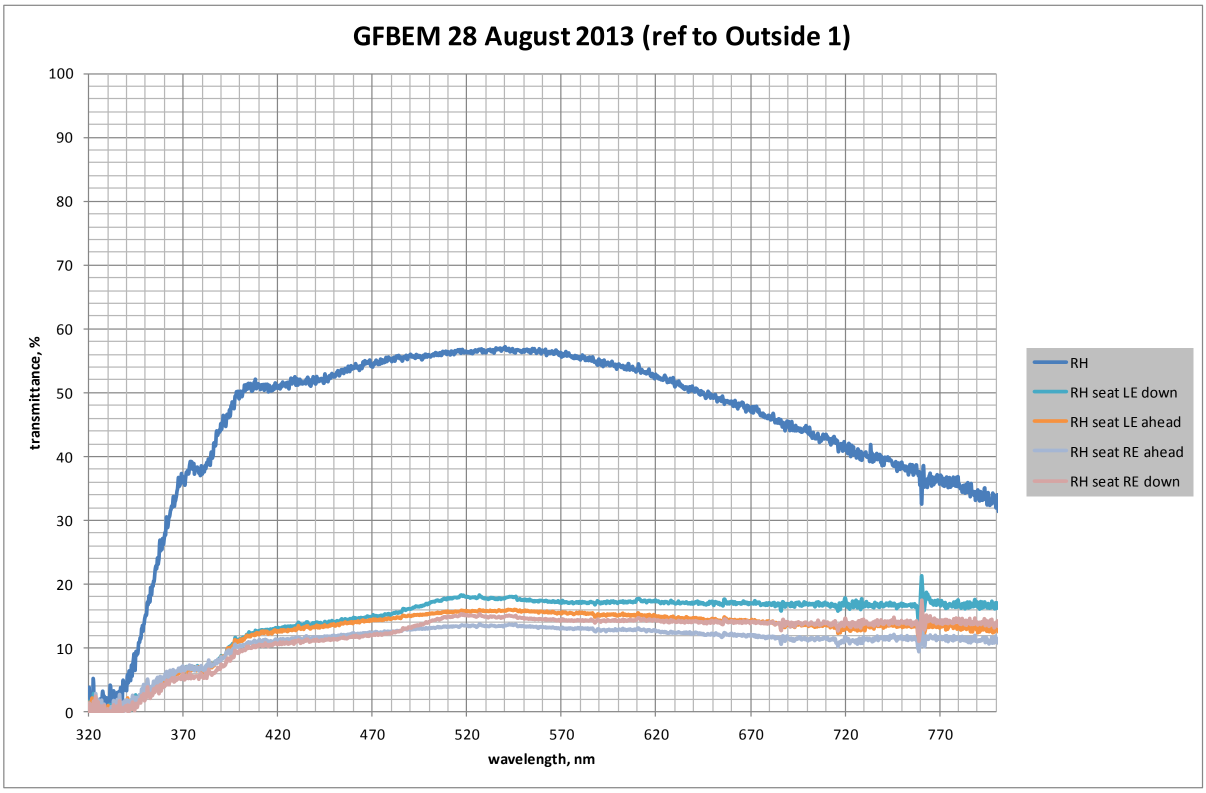

Figure 5-e Comparison of spectral curve at the right hand (RH) windshield and at the pilot's right and left eye level facing ahead and down towards instruments.

The ratio of the signal at the windshield to the signal in eyes ahead position from the right hand seat of aircraft 13 is shown in Figure 5-f. It can be seen that a relatively constant ratio is present across the spectrum. The data captured assumes that the source is constant and was not affected by changes in cloud cover. There was a 16 minute interval between measurement at the windshield and the first measurement at eye position. More variation is seen in the UVA range due to a lower signal to noise ratio compared to the visible spectrum.

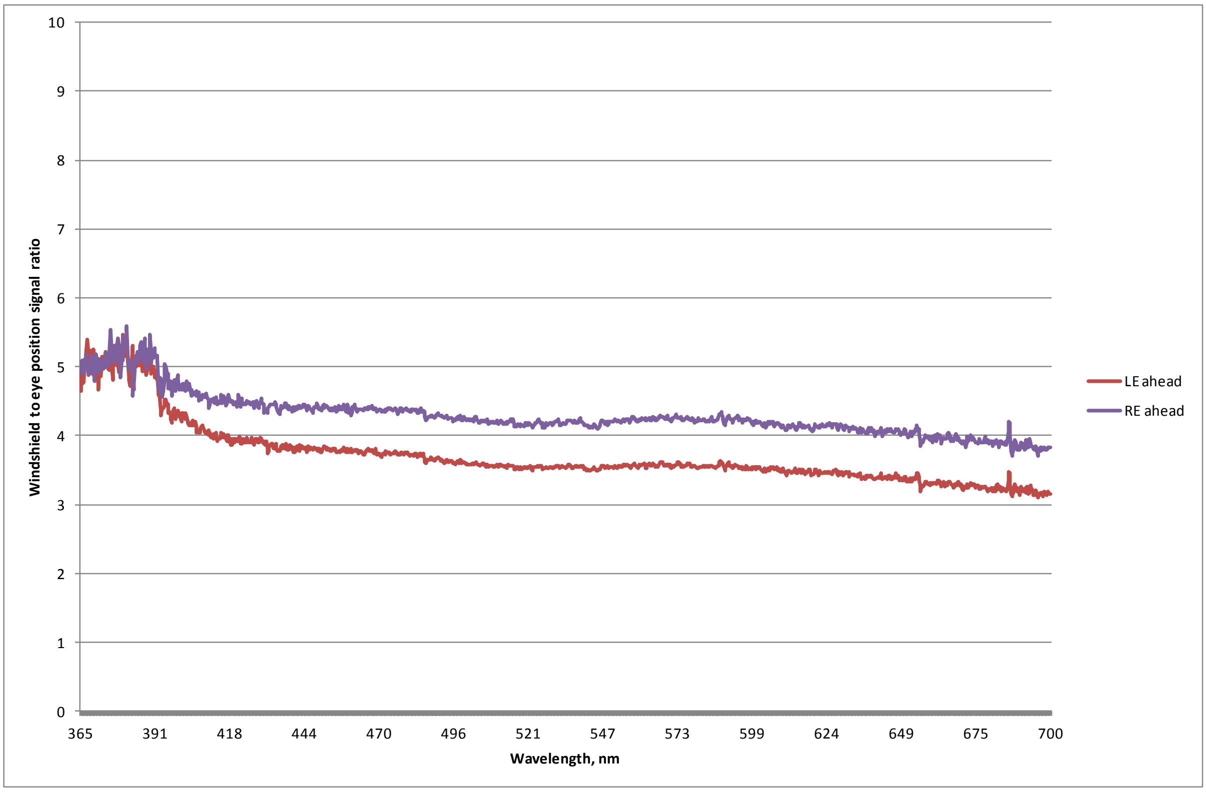

Figure 5-f Ratio of signal strength between spectrum at windshield and at pilot eye level. A flat line indicates a constant ratio.

5.12 Approval of spectrometer for flight

In order to obtain data during flight, a series of procedures were undertaken in order to firstly ensure that the equipment would not interfere with any aircraft systems and secondly to maximize the likelihood of gaining airline approval to carry the equipment and researcher on the flight deck.

A letter was drawn up which briefly explained the research, the equipment, any potential costs to the airline and contained a request for airline co-operation. This was signed by the CAA Chief Medical Officer and Head of Flight Operations (appendix H). A risk assessment document (appendix G) was also drawn up which described the equipment, its intended use and a series of technical specifications. The accuracy of spectrometer product data within this document was confirmed with manufacturers. The document also contained an analysis of how the equipment could be affected in the normal flight deck environment at altitude, any foreseen way in which the equipment could affect aircraft systems and how the equipment may be affected by an emergency event such as de-pressurisation or fumes in the cockpit.

To facilitate free movement of the researcher through airport security and to the aircraft, airside security passes were requested through the CAA and were gained following visits to airport security for both London Gatwick and London Heathrow airports.

Before approaching airlines, it was felt that an analysis should be carried out to identify where the equipment would be optimally placed and secured. In order to do this, a company with a Boeing B737 simulator in West Sussex were contacted and agreed to allow access during a short available slot while the simulator was not in use. For this assessment, as well as a professional pilot representative from the company operating the simulator, a colleague from PHE was also in attendance and advice was sought to determine the most practical position of the spectrometer probe balancing the requirements of ensuring successful data collection during flight whilst not interfering with safe flight operations.

It was determined that the optimum probe position should be placed facing forward toward the front windshield. To ensure a strong signal, the probe would be placed close to the windshield, as signal strength would decrease further back inside the cockpit away from the windows. The probe would be secured against the frame between front and side windows and be placed in a lower position in order be away from the pilot sight line. A secure place for the spectrometer, shutter, batteries and palmtop was decided as on the floor, behind and to the side of the pilot's seat. The fibre optic and illuminance meter cable would be secured together along the side window sill. The exact position could be altered dependent on variations in aircraft type. It was recognised that the B737 had a small cockpit area compared to other jet airline aircraft types. Some aircraft types had sliding side windows which are used as an emergency exit for the flight crew. Therefore it was also recognised that the securing of the probe should not hinder the ability of the pilot to open this window in an emergency. Due to the small size and low weight of the spectrometer and illuminance UV recorder probes, the two were secured together by enlarging the hole at the top of the illuminance UV recorder probe such that the spectrometer probe tightly fitted preventing any movement or potential separation during flight. The side of the probe could then be secured to (and removed from) the aircraft frame using Velcro.

The equipment could be positioned on left or right sides. The standard fibre optic cable was 2 metres in length. It was felt that whilst this was sufficient for the B737, it may not be long enough for other aircraft. For this reason a second fibre optic cable of 3m length was carried. The cable for the illuminance UV recorder required an extension length in order to be able to place the data unit with the spectrometer equipment.

During 2012-2013, a number of airlines were approached, generally via the airline's Head of Flight Operations. The research letter and risk assessment document were included for information. Further meetings in person were arranged, where requested by the airline so that the study proposal could be discussed further. Monarch Airlines agreed to carry the equipment and researcher onboard once a company avionics engineer had given approval and once the securing of the equipment had been complete to the satisfaction of the captain of the flight. Due to limited time available in busy scheduling, the avionics engineer was arranged to attend the aircraft just prior to the crew arriving for the first flight. It was agreed that if the engineer was not satisfied, neither the equipment nor researcher would remain onboard during the flight.

Airport security was notified prior to the researcher taking the equipment airside. Following this, arrangements were made to always ensure that the researcher carried airside security ID, passport, boarding pass, CAA research approval letter and risk assessment documents to pass through airport security.

5.13 Sample size

There were several potential barriers described in section 5.12 to be overcome in order to capture in flight data. This had the potential to limit the number of data recording flights. However, in order to capture as varied data as possible, the aim was to collect data on board flights of varying routes, different aircraft types and during different times of year. It was recognised that each flight would generate large amounts of data which would in turn affect the complexity of data analysis.

Therefore it was expected that five to ten appropriately selected flights could generate data likely to capture typical irradiances expected during flight.

5.14 Summary

Chapter 5 offers description of the equipment used for data collection which is detailed in subsequent chapters. The next chapter describes the measurements captured during flight. Chapter 7 details measurements taken at a series of office workstations in order to offer a comparison of occupational ocular radiant exposure. This equipment was also utilised for aircraft windshield and visor ground transmittance measurements (chapter 8) and sunglass filter transmittance measurements (chapter 9). Where differences in measurement methods occur, these are described in the relevant chapter. However, the calibration procedure, software and equipment limitations described in this chapter apply for all subsequent chapters.

6. Chapter 6 Measurements during flight (Phase 2)

CHAPTER OVERVIEW

This chapter presents data obtained with the HR4000 spectrometer and associated equipment sited in aircraft cockpits during six airline flights (11 sectors) and four helicopter flights (8 sectors). Ocular exposure of the unprotected eye to UV and the light hazard has been calculated for all flights and is compared to ICNIRP guideline limits. The variation during flight of UVA, blue light and illuminance levels will be demonstrated and presented together with data of erythemal weighted irradiance and UVA and blue light hazard ratios. Azimuth flight plots will be introduced to assist the understanding of differences in irradiance levels measured during each flight and for comparison of flights.

6.1 Method

A series of data collection sessions during flights were successfully arranged with Monarch Airlines. It was planned to capture data on various routes and at different times of the year. However flight availability was limited due to a number of factors including ensuring that flights were undertaken from London Gatwick airport during daylight hours, that there was prior agreement from the captain of the flight, that sufficient notice was available to arrange ticketing for the researcher and that there were no other flight operational constraints such as flights where the jump seat would be occupied by a third pilot.

In flight data were collected on the following dates and take off to landing times. Times shown are Coordinated Universal Time (UTC) or UTC+1 for British Summer Time (BST):
16 May 2012: London Gatwick to Faro, Portugal (0628-0851 UTC+1) on board an Airbus A320
16 May 2012: Faro, Portugal to London Gatwick (1026-1253 UTC+1) on board an Airbus A320
22 May 2012: London Gatwick to Barcelona, Spain (0651-0824 UTC+1) on board an Airbus A320
22 May 2012: Barcelona, Spain to London Gatwick (1013-1206 UTC+1) on board an Airbus A320
26 May 2012: London Gatwick to Barcelona, Spain (0656-0834 UTC+1) on board an Airbus A320

26 May 2012: Barcelona, Spain to London Gatwick (1004-1150 UTC+1) on board an Airbus A320

21 November 2012: London Gatwick to Tobago (0930-1912 UTC) on board an Airbus A330

1 March 2013: London Gatwick to Alicante, Spain (0803-1010 UTC) on board an Airbus A321

1 March 2013: Alicante, Spain to London Gatwick (1143-1354 UTC) on board an Airbus A321

21 August 2013: London Gatwick to Rhodes, Greece (0924-1304 UTC+1) on board a Boeing 757

21 August 2013: Rhodes, Greece to London Gatwick (1420-1812 UTC+1) on board a Boeing 757

Airport	**International Code**	**Latitude**	**Longitude**
London Gatwick	LGW	51.150837	-0.177416
Faro, Portugal	FAO	37.017596	-7.968545
Barcelona, Spain	BCN	41.30303	2.07593
Tobago	TAB	11.152541	-60.839684
Alicante, Spain	ALC	38.287098	-0.557381
Rhodes, Greece	RHO	36.405278	28.086111

Table 6-a Summary of airport location and international code.

Throughout each flight, manual readings were taken with the second illuminance UV recorder and were recorded on a specifically designed template (appendix O). Readings were taken as described in sections 5.7 and 5.9. A reading was documented once the illuminance UV recorder reading had stabilised. In order to ensure accurate time logging, the researcher’s wristwatch and time set on the palmtop were matched. In addition to the time stamped illuminance readings, further details were collected of push-back, taxy, take off and landing times. The researcher also recorded altitude data from view of aircraft instruments from the jump seat. Observations were also made of the use by either pilot of sunglasses or any aircraft visors. Both initiation and termination times of eye protection strategies were recorded. Finally, observations were made from the jump seat of weather conditions such as cloud cover.

Data were also collected on a series of helicopter flights from Dyce airport, Aberdeen to North Sea oil platforms with Bristow helicopters. During the two day visit to Aberdeen, additional flight operational constraints were found. The number of passengers scheduled to be flown on a particular flight meant that the maximum take-off weight of the aircraft could be exceeded by carrying an additional passenger (the researcher) on board.

Additionally, in order to secure the spectrometer and illuminance meter probes against aircraft structure whilst being near the front windshield and out of the pilot's line of sight, the optimum location found was in a lower and more forward position than for aeroplane flights. The fibre optic and illuminance meter cables were secured above the side windows. This was particularly important in helicopter types with side doors for the pilot to enter and exit the aircraft. Due to this longer fibre optic cable route, it was necessary to use the 3m fibre optic cable for some flights. A secure location was found for the spectrometer away from other equipment to ensure optimum temperature control during data collection.

In flight data were collected on the following dates including takeoff and landing times (UTC+1):
9 April 2013: Dyce airport to Claymore A (1049-1140) on board an Aerospatiale AS332 Super Puma
9 April 2013: Claymore A to Dyce airport (1159-1244) on board an Aerospatiale AS332 Super Puma
9 April 2013: Dyce airport to Triton (1445-1545) on board an Aerospatiale AS332 Super Puma
9 April 2013: Triton to Dyce airport (1600-1651) on board an Aerospatiale AS332 Super Puma
10 April 2013: Dyce airport to Judy (1134-1254) on board a Sikorsky s-92A
10 April 2013: Judy to Dyce airport (1309-1409) on board a Sikorsky s-92A
10 April 2013: Dyce airport to Judy (1511-1630) on board a Sikorsky s-92A
10 April 2013: Judy to Dyce airport (1647-1754) aboard a Sikorsky s-92A

Airport / oil platform	International Code	Latitude	Longitude
Aberdeen, Scotland	ABZ	57.200253	-2.204186
Claymore A		58.4 approx	-0.3 approx
Triton		57.1 approx	0.9 approx
Judy		56.7 approx	2.3 approx

Table 6-b Summary of Aberdeen airport and approximate oil platform locations

Due to the aircraft take-off weight constraints described above, the researcher was unable to be onboard to take manual readings for the first flight on 9 April and the second flight on 10 April. Here, the spectrometer and illuminance meter data logger were positioned, secured and programmed before flight for automated data collection. The equipment was then retrieved when safe to do so once the aircraft had returned to Dyce airport.

The researcher was present on flight 8 (the second flight on 9 April) which was on the same aircraft type as flight 7 (the first flight on 9 April) and was also present on flight 9 (the first flight on 10 April) which was the same aircraft as flight 10 (the second flight of that day). Therefore, in order to estimate pilot exposure during the flights where no manual data were captured, data were used from the other flight conducted on the same day on board the same respective aircraft type. The average ratio of signal measured between the two illuminance UV recorders for both 'eyes ahead' and 'eyes toward instruments' measurements were applied to the flights where no manual readings were taken. Additionally, Bristow helicopters were able to provide time stamped records of these two flights including take off and landing times and altitude data.

Data from the illuminance UV recorders were converted to tab delimited format. Both these and spectrometer data were analysed using Microsoft Excel 2007. For each spectral reading, the counts per second (cps) values were calculated by subtracting the dark counts from the counts and dividing the value by the integration time for each wavelength step. A calibration factor was applied, where indicated. Regions 1, 2 and 3 were assessed to determine whether spectral stitching was required (section 5.8). Blue light and erythemal action spectra were applied in separate calculations. Summary data was created for each 10 minute spectrometer reading which included UVA irradiance, blue light weighted irradiance, illuminance, blue light and erythemal weighted readings and hazard ratios. A full summary document was created for each flight incorporating data from both illuminance UV recorders and flight information. Blue light weighted radiance and UVA dose throughout flight were calculated.

The ratio between the two illuminance UV recorders at each timed measurement was calculated. For calculation of ocular exposure, each pair of ratios (for both eyes ahead and down) was applied to time matched spectrometer data. For cases where illuminance UV recorder and spectrometer data were not time matched, spectrometer data were calculated using the closest two readings and assumed a constant change over the 10 minute interval. For example, where an illuminance UV recorder reading was 2 minutes difference from the first spectrometer reading and 8 minutes to the next, the estimated spectrometer reading would be 20% of the difference between spectrometer readings from the first reading. Ocular dose in both eyes ahead and eyes down position were calculated and a further dose calculation was made including time during turn around at destination. A calculation of radiant exposure was made based on the turnaround time and a mean of the last reading from the outbound sector and first for the inbound sector which were both at the stand at the destination airport.

Using time and altitude data, ground and cruise altitude data were identified and compared for calculation of the mean increase in irradiance and illuminance at altitude. For these calculations, readings taken during climb and descent were not used.

Blue light retinal exposure was calculated by averaging radiance over a solid angle. The effective radiance may be lower than actual radiance; however for the purposes of pilot exposure calculations, it was assumed that there is a uniform sky which was considered as a large source. The azimuth flight plots (section 6.2.4) indicate a minimal proportion of flight time where the solar disc was directly visible through the front windshield. Additionally, visors would be more likely to be used in these circumstances (section 4.11) which will attenuate the irradiance over that particular area of field.

ICNIRP exposure limits are expressed as spectrally weighted radiance dose and suggest a conservative averaging angle of 0.11 radian (6.3°) for exposures of over 10,000 seconds (around 2hrs 47min). A larger solid angle could be used following appropriate task analysis. For the purposes of calculating pilot exposure, data from the Airbus binocular visibility charts (section 1.5.6) were used. To calculate the angle subtended at the eye, the front windshield only was used as viewing through the other windows is likely to involve head and eye movements. Additionally the pilot's attention would be generally directed ahead and through the front windshields when not towards the instruments. For the Airbus A320, an approximated area of 60° horizontally and 50° vertically was used. Similarly, for the Airbus A330, an approximated area of 65° horizontally and 45° vertically was used. In the cases of a non-circular source, ICNIRP (2013) recommend that the angle subtended by the source at the eye is taken as the mean of the shortest and longest dimension. This is 55° (0.96 rad) in both cases.

The solid angle was calculated as $(\pi \times 0.96^2)/4$. The equivalent spectrally weighted irradiance (W/m^2) was divided by this value to derive the radiance ($W/m^2.sr$) at the retina.

An instantaneous sampling solid angle of around 0.2 rad (11 deg) has been suggested (ICNIRP, 2013). This is the angle beyond which the injury threshold of radiant exposure does not change with increasing size, assuming a uniform source. As radiance is defined as the radiance flux per unit area and unit of solid angle, a larger solid angle such as the open view received by the pilot would not significantly affect radiance values and, assuming the sky is a uniform source, the radiance measured with open field as has been done in this study has been considered the same as if measured with a restricted field.

6.2 Results

6.2.1 Flight summary

Data were captured throughout a total of 11 sectors (5 return flights and 1 outbound sector). A summary is shown below of aircraft type, flight duration and cruising altitude for aeroplane (Table 6-c) and helicopter (Table 6-d) flights.

Flight	Date	Destination	Aircraft type	Max altitude (Flight Level)	Duration excl. taxy (min)	Duration incl. taxy (min)	Total duration incl. turnaround (min)
1a	16/05/2012	Faro	A320	370	143		385
1b	16/05/2012	LGW	A320	360	147		
2a	22/05/2012	Barcelona	A320	390	93		315
2b	22/05/2012	LGW	A320	380	113		
3a	26/05/2012	Barcelona	A320	330	98		294
3b	26/05/2012	LGW	A320	380	106		
4	21/11/2012	Tobago	A330	400	555	588	
5a	01/03/2013	Alicante	A321	350	127	151	376
5b	01/03/2013	LGW	A321	340	131	150	
6a	21/08/2013	Rhodes	B757	370	220	235	544
6b	21/08/2013	LGW	B757	380	232	247	

Table 6-c Summary of aeroplane flights undertaken.

Flight	Date	Destination (oil platform)	Aircraft type	Max altitude (ft)	Duration excl. taxy (min)	Total duration incl. taxy/ turnaround (min)
7a	09/04/2013	Claymore A	AS332	3,000	50	115
7b	09/04/2013	ABZ	AS332	1,100	45	
8a	09/04/2013	Triton	AS332	3,000	60	135
8b	09/04/2013	ABZ	AS332	2,000	51	
9a	10/04/2013	Judy	S-92a	3,000	80	174
9b	10/04/2013	ABZ	S-92a	2,000	60	
10a	10/04/2013	Judy	S-92a	3,000	79	163
10b	10/04/2013	ABZ	S-92a	2,000	67	

Table 6-d Summary of helicopter flights undertaken

6.2.2 Aeroplane spectrometer data

The results in this section relate to the data captured by the spectrometer. The irradiance results are significantly higher than the data presented for ocular exposure due to the forward location of the probe, its independence of aircraft structure and independence of pilot use of aircraft visors or blinds. A summary of spectrometer data collections for each flight are shown in Table 6-e.

Flight	No of complete spectra	No of saturated spectra	No of spectra with non-operational shutter	No of spectra requiring stitching
1 (a+b)	37	0	1	0
2 (a+b)	30	6	0	0
3 (a+b)	28	2	0	0
4	67	1	30	0
5 (a+b)	33	0	0	0
6 (a+b)	55	0	18	0

Table 6-e Summary of the spectrometer data measurements for aeroplane flights together with the number of saturated readings (discarded), number of reading where the shutter was not functional and the number of spectra requiring stitching.

Each complete spectrum consisted of six measurements: a spectral and dark measurement for each of the three regions. A number of spectral readings were ignored due to saturation of the signal for part of the spectra. This occurred occasionally on early flights and modifications were made to the settings of regions 2 and 3 in ASAS (section 5.7) which prevented further reoccurrence. The changes to settings involved a reduction of maximum target count and widening the band width range to prevent pixel leakage.

A number of spectra were affected by a fault with the optical shutter (see section 6.2.21.2). For each of these data sets, an appropriate dark reading was selected from a series measured using the HR4000 in the PHE lab settings at various temperatures and integration times.

Stitching was rarely required as there was generally a strong signal with all regions showing good correlation. Additionally, analysis of region 3 data consistently showed equivalent UV data to region 1 alone. Therefore, unless stitching was required, region 1 data were used.

6.2.3 Aeroplane UVA, blue light and illuminance data

No significant signal above background noise was found in the UVB range on any flight. Total UVA for each spectra was calculated as the sum of unweighted irradiances of each wavelength from 315-400nm measured in W/m^2. Blue hazard was calculated for each spectra using the blue light hazard weighting function from 300-700nm. Illuminance was recorded at each spectrometer data collection and by both illuminance UV recorders.

6.2.3.1 Flight 1 - Faro

A summary of UVA and blue light levels during flight are shown in Figure 6-a. The areas of the graph shaded in green represent the periods of time where the aircraft was at ground level while the blue shaded areas represent those periods of time during which the aircraft had reached cruise level flight at altitude. The unshaded areas between represent the time during which the aircraft was climbing or descending. In order to ensure sufficient spectrometer battery power, the equipment was shut down while the aircraft was parked at the stand at the destination airport and switched on just prior to push back. This gap in data collection is represented in Figure 6-a by double lines across the UVA and blue light irradiance data.

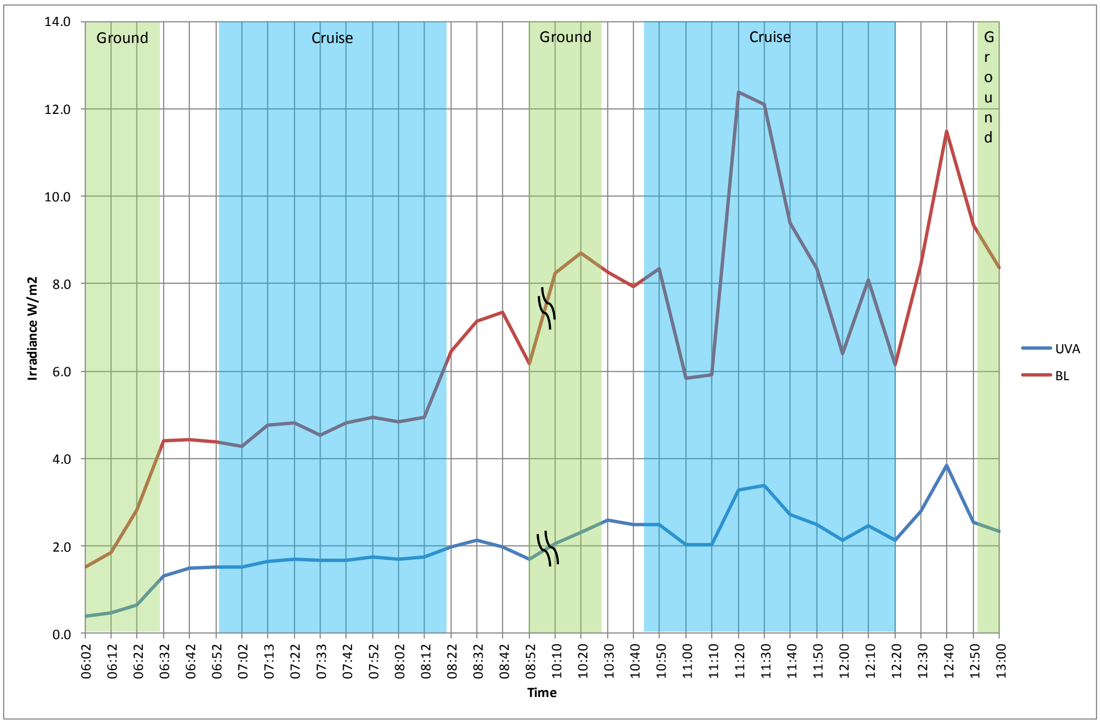

Figure 6-a Flight 1 summary of UVA and blue light.

There was no significant cloud at departure. Conditions were clear with surface in sight. Scattered thin layer cloud was noted below from 07:40 with surface remaining visible. High level thin cloud was noted from 08:10 until start of descent. During descent, the aircraft was briefly flying through light cloud at 08:30 with surface remaining visible.

On the return sector, there was no significant cloud at departure. From 10:45, there was light cloud seen below obscuring view of the surface. The cloud below thinned and surface was visible from 10:50. There was high altitude thin cloud cover above the aircraft. An increase was seen between spectrometer readings at 11:10 and 11:20; however no obvious changes of flight conditions were noted. Subtle heading changes are required during cruise flight as the aircraft navigates through a series of airways (see section 1.5.2). A slight heading change is likely to have occurred around this point in time which may have affected the relative position of the sun to the aircraft and spectrometer. By 11:30, there was no cloud observed until during descent where the aircraft passed through a layer of cloud at 12:44.

Illuminance measured by the spectrometer and illuminance UV recorder are shown in Figure 6-b and Figure 6-c respectively.

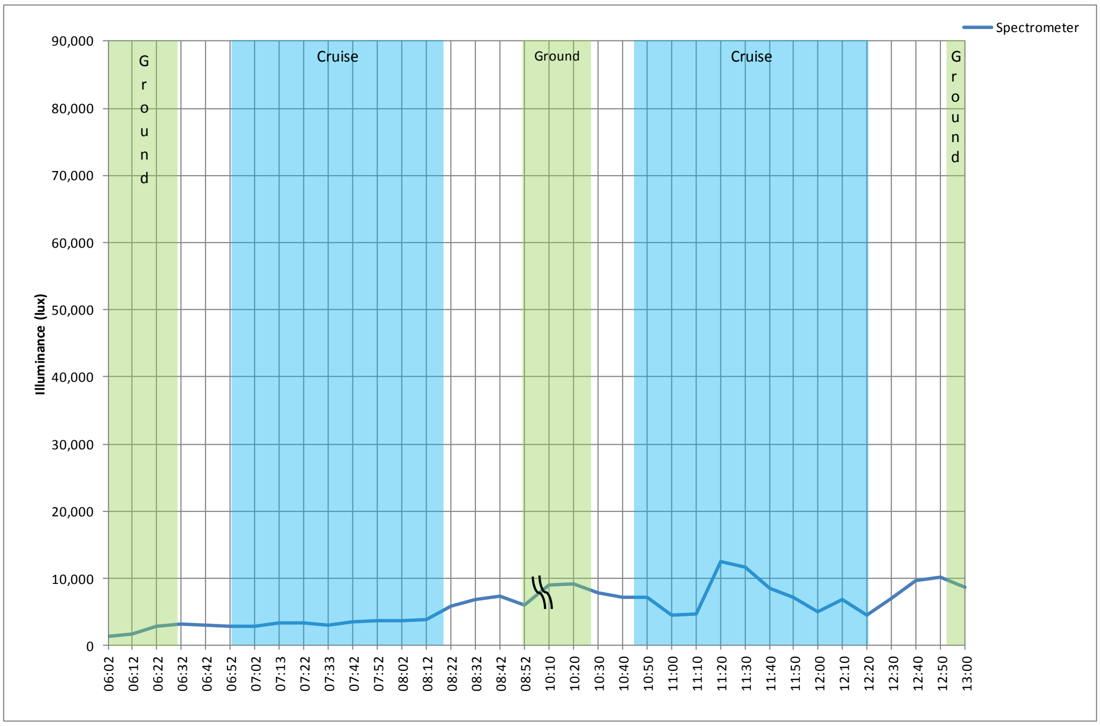

Figure 6-b Illuminance measured by spectrometer during flight 1.

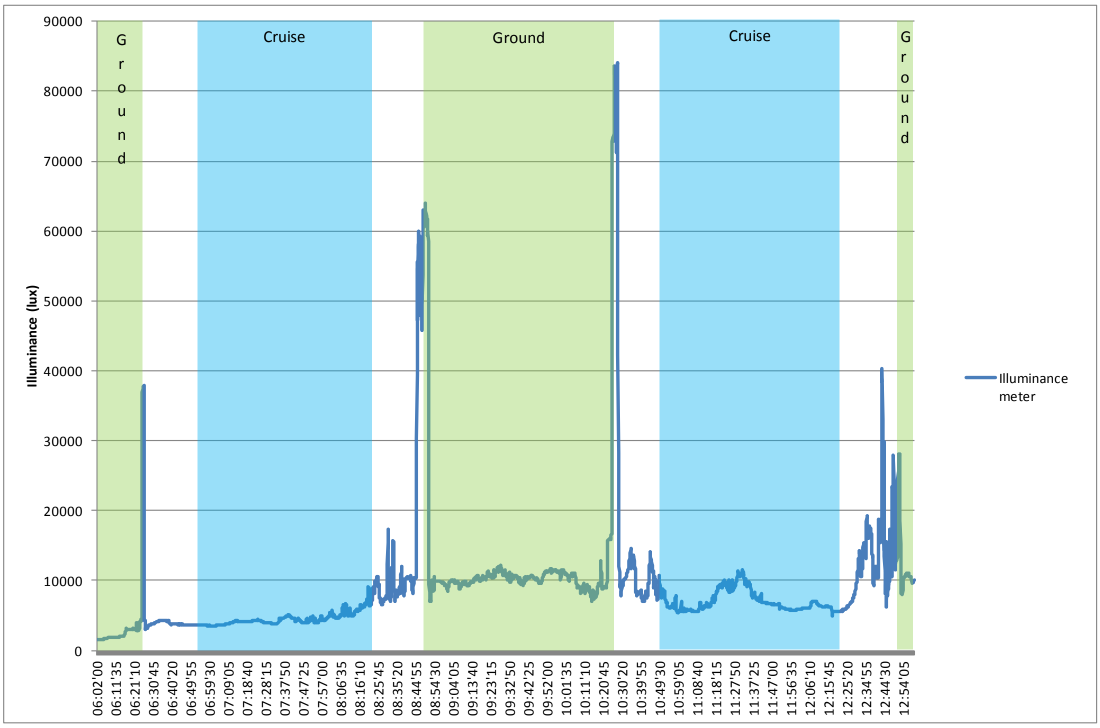

Figure 6-c Illuminance measured by illuminance UV recorder during flight 1.

A series of short spikes in illuminance can be seen from the illuminance data and occurred during approach, take off or taxy as the aircraft was manoeuvring. This may have lasted for only one minute, such as the first spike whilst taxiing at London Gatwick airport. This temporary increase occurred at 06:25 and fell between the 10 minute intervals for spectrometer readings. The cause of these large increases are likely to be due to direct sunlight radiation being collected by the probes and do not occur during the stable phases of flight during cruise (or when parked at the stand).

To ensure sufficient power to the palmtop for the return flight, the palmtop was switched off during turnaround, however the illuminance meter continued to collect illuminance data while the aircraft was parked at the stand.

UVA readings peaked at 3.85 W/m^2 at 12:40. Blue light peaked at 12.4 W/m^2 at 11:40. The total UVA radiant exposure measured by the spectrometer (excluding turnaround time) was 4.39 x10^4 J/m^2. The total blue light radiant exposure measured during the same period was 1.43x10^5 J/m^2. Comparing the illuminance data collected by both illuminance UV recorder and spectrometer resulted in a correction factor of 1.37. This would increase UVA to 6.01 x10^4 J/m^2 and blue light to 1.96 x10^5 J/m^2.

6.2.3.2 Flight 2 – Barcelona

A summary of UVA and blue light levels during flight are shown in Figure 6-d.

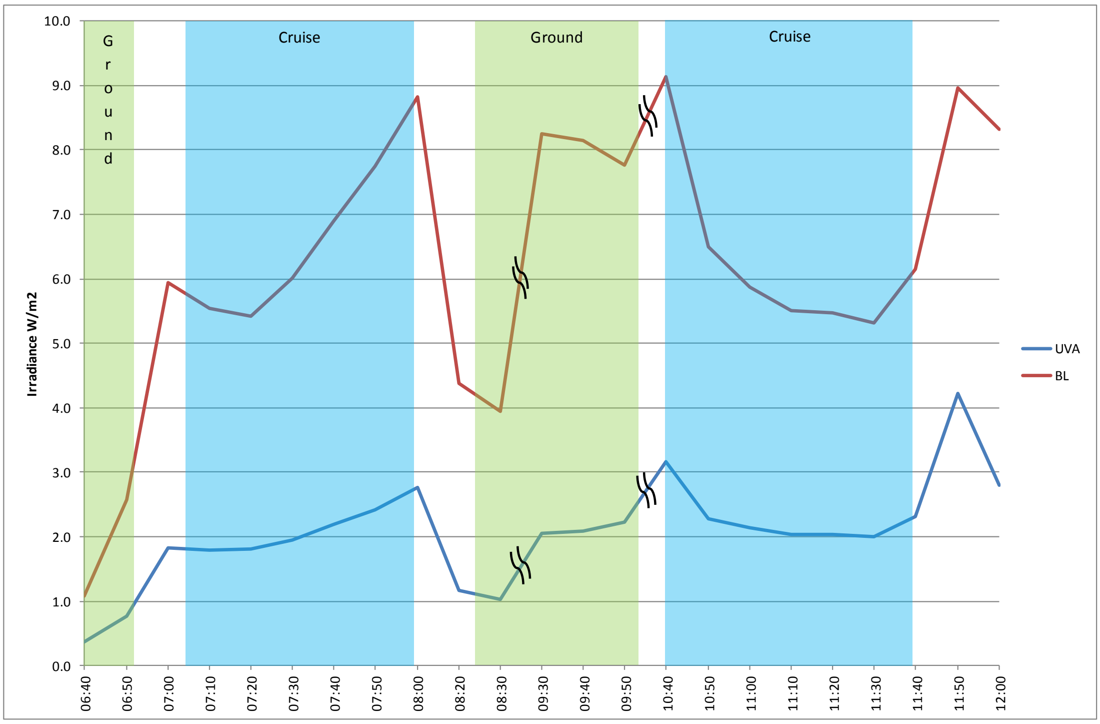

Figure 6-d Flight 2 summary of UVA and blue light.

Weather conditions at departure were dry with overcast low cloud. The aircraft was above cloud 1 minute after take-off. Surface remained visible throughout the remainder of the outbound flight although increasing cloud was noted during descent and approach to Barcelona.

On the return flight, there was thin broken cloud noted at the departure airport. A short delay was experienced during taxy due to a bird strike encountered by the previous departing aircraft. Thin cloud layers were climbed through to give broken cloud below the aircraft until 10:50 after which no cloud was noted for the remainder of the flight.

Illuminance measured by the spectrometer and illuminance UV recorder are shown in Figure 6-e and Figure 6-f respectively.

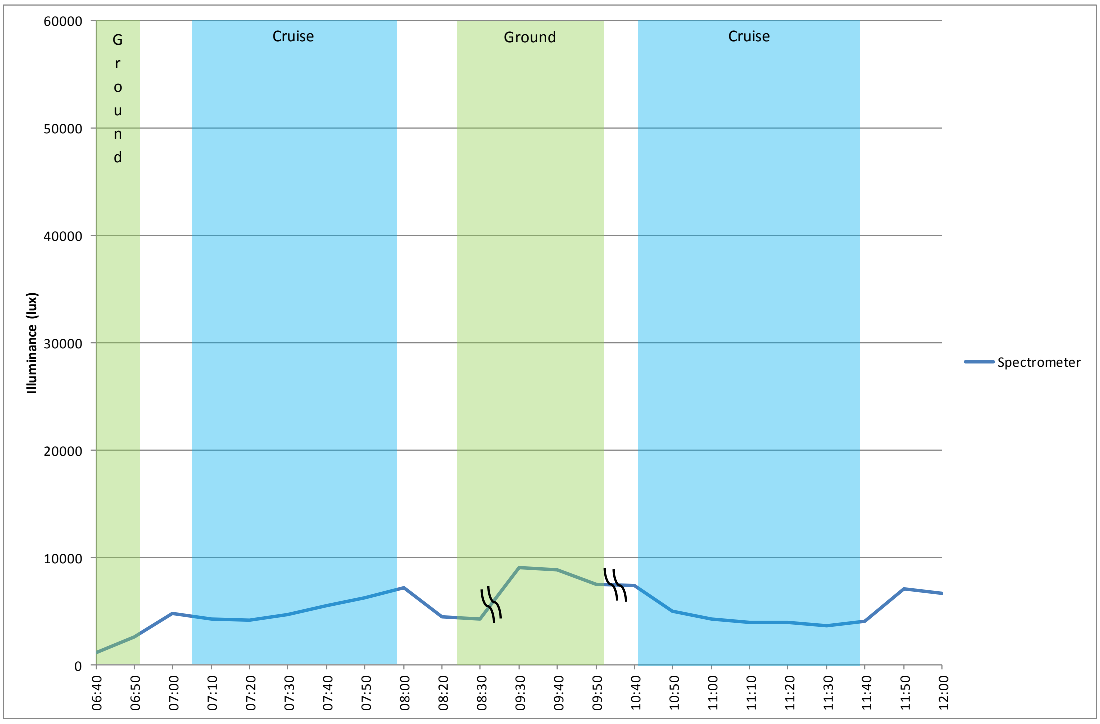

Figure 6-e Illuminance measured by spectrometer during flight 2.

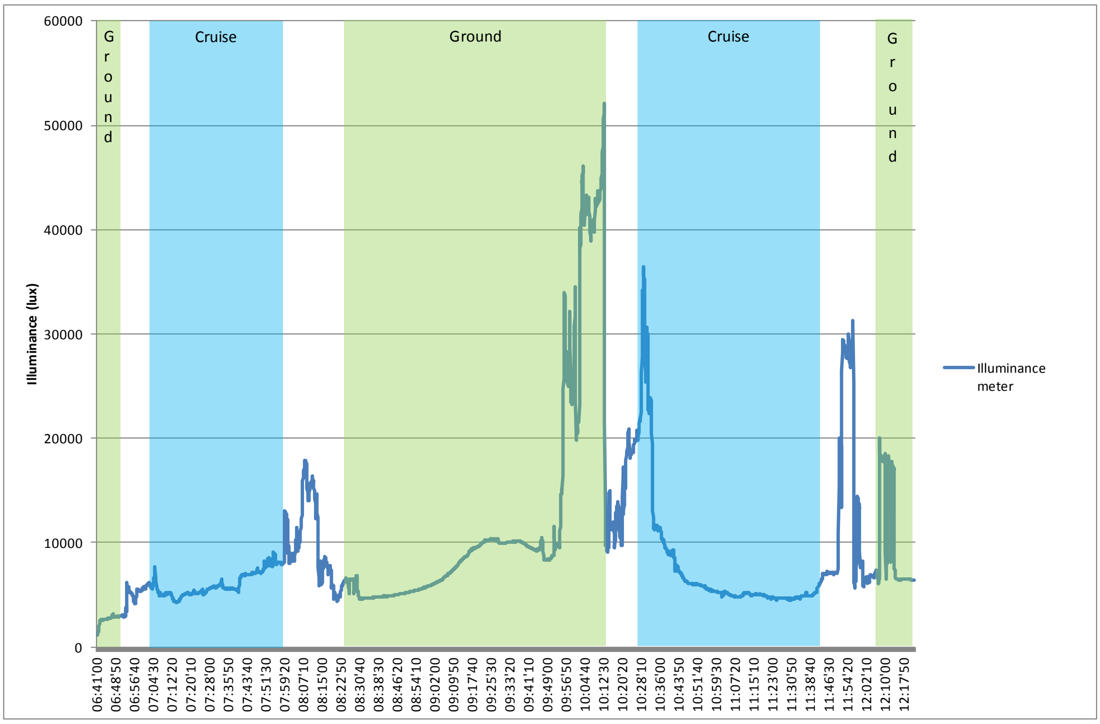

Figure 6-f Illuminance measured by illuminance UV recorder during flight 2.

The spectrometer was switched off during turn around therefore less ground data is available in Figure 6-e. Additionally, the following six spectral reading were excluded due to signal saturation:

0810 – during descent to Barcelona
1000-1030 - during taxy, take off and climb to altitude from Barcelona
1210 – after landing at London Gatwick

These coincide with sharp increases in illuminance seen Figure 6-f and may account for the saturated readings. As the spectrometer samples and estimates integration time between readings (section 5.7), a longer than necessary integration time may have been used during actual data capture where irradiance levels have sharply increased and were higher than anticipated.

Illuminance levels showed greatest stability during cruise and showed greatest variation during take-off, approach and manoeuvring during taxy. The largest increase in illuminance level was recorded was during taxy at Barcelona airport. UVA readings peaked at 4.21 W/m^2 at 11:50. Blue light peaked at 9.14 W/m^2 at 10:40. The total UVA radiant exposure measured by the spectrometer (excluding saturated data and turnaround time) was 3.34 $x10^4$ J/m^2. The total blue light radiant exposure measured during the same period was $1.01x10^5$ J/m^2. Comparing the illuminance data collected by both illuminance UV recorder and spectrometer resulted in a correction factor of 1.30. This would increase UVA to 4.34 $x10^4$ J/m^2 and blue light to 1.32 $x10^5$ J/m^2.

6.2.3.3 Flight 3 - Barcelona

A summary of UVA, blue light and illuminance levels during flight are shown in Figure 6-g. In order to present meaningful graphical data for all flights, the y axis scales for irradiance and illuminance between flights may change.

No significant cloud was noted from departure at London Gatwick until 08:15 during descent where a layer of cloud was passed through by 08:20. On departure, light scattered cloud was noted at the aerodrome. The aircraft was above cloud level four minutes after take-off. No significant cloud was seen below from 10:14 to 10:27. A cloud layer below obscured view of surface from 10:27 to 10:55 after which there was no cloud noted during the remainder of the flight. The sharp increase around 10:00 coincides with taxiing for takeoff at Barcelona airport.
No pre-programmed data from illuminance UV recorder were available during this flight. Data were read manually from both units at the same time as programmed spectrometer readings.

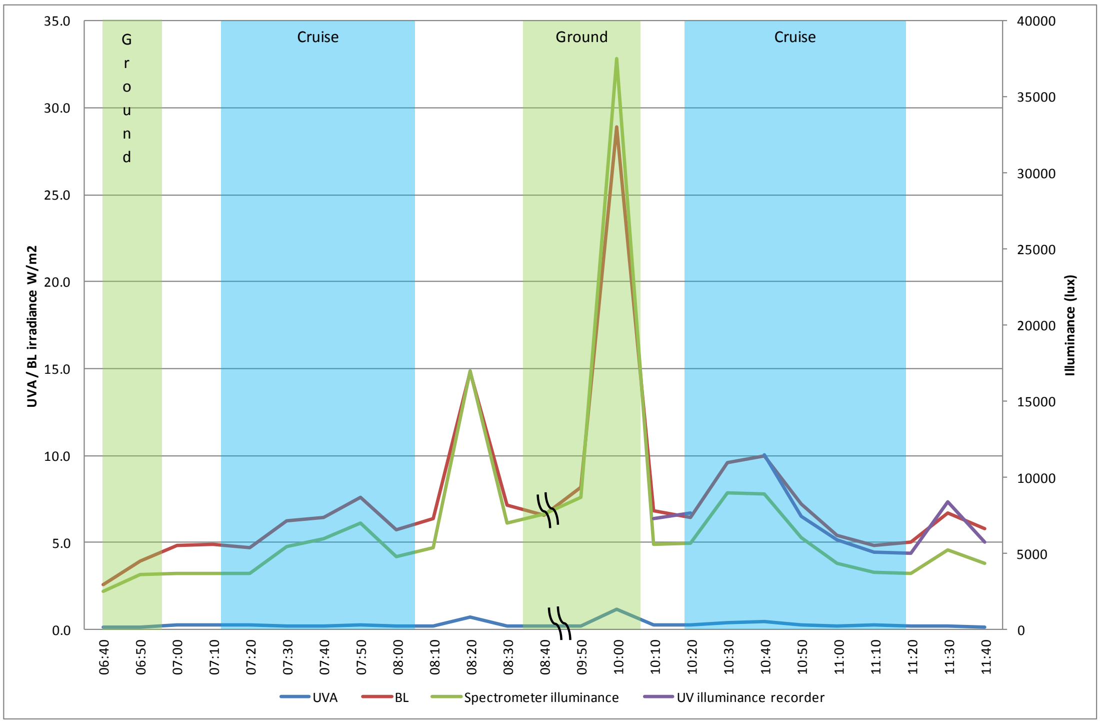

Figure 6-g Flight 3 summary of UVA and blue light together with data recorded manually from the illuminance UV recorder.

Two spectral readings were excluded due to data saturation. These were 1150-1200 corresponding to immediately after landing at London Gatwick. UVA readings peaked at 1.14 W/m^2 at 1000. Blue light peaked at 28.9 W/m^2 at 1000. The total UVA radiant exposure measured by the spectrometer (excluding saturated data and turnaround time) was 4.24 x10^3 J/m^2. The total blue light radiant exposure measured during the same period was 1.12x10^5 J/m^2.

Good correlation was seen between blue light data and overall lux in both spectrometer and illuminance meter.

6.2.3.4 Flight 4 – Tobago

A summary of UVA, blue light and illuminance levels during flight are shown in Figure 6-h.

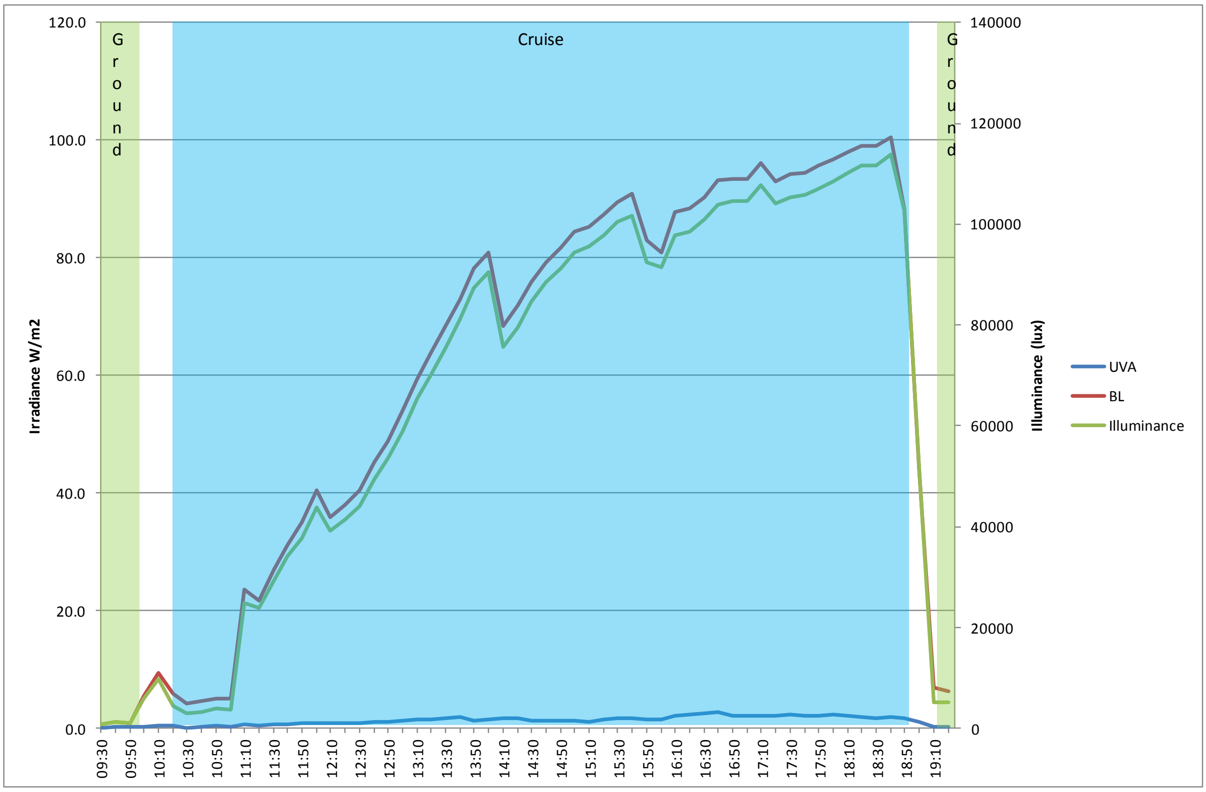

Figure 6-h Flight 4 summary of UVA and blue light.

The weather at London Gatwick was overcast with light rain on departure. At 10 minutes after take-off, separate cloud layers were above and below the aircraft. At 10:10, there was cloud layer noted below only and by 11:00, no significant cloud was noted with surface being visible. A cloud layer obscuring the surface was noted from 16:10 to 16:45. The aircraft passed through a light layer of cloud (duration of one minute) at 18:59 during descent.

The aircraft passed across the jet stream borders at approximately 11:40 and 15:00. Data from the illuminance UV recorder is shown in Figure 6-i. Data shows good correlation with the spectrometer although there was a sudden drop in recorded illuminance at 11:41 lasting 10 seconds and a further drop at 13:45 lasting 1 minute. Although no observed changes in conditions occurred at these times, it is possible that radiation gathered by the probe may have been briefly interrupted by objects such as a hand or checklists passing in front of the probe. However, the cause is not known.

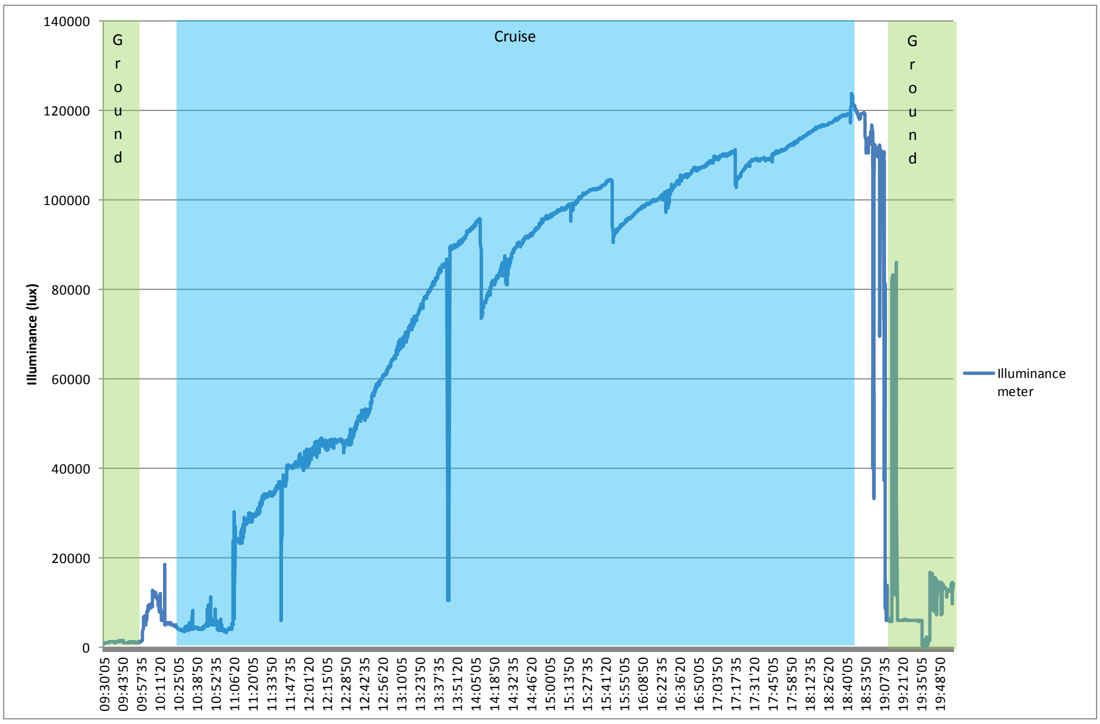

Figure 6-i Illuminance measured by illuminance UV recorder during flight 4.

UVA readings peaked at 2.82 W/m^2 at 16:40. Blue light peaked at 100.5 W/m^2 at 18:40 with illuminance measured at 113,700 lux. The total UVA radiant exposure measured by the spectrometer was 4.57 $x10^4$ J/m^2. The total blue light radiant exposure measured during the same period was $2.13x10^6$ J/m^2. Comparing the illuminance data collected by both illuminance UV recorder and spectrometer resulted in a correction factor of 1.06. This would increase UVA to 4.85 $x10^4$ J/m^2 and blue light to 2.25 $x10^6$ J/m^2.

6.2.3.5 Flight 5 – Alicante

A summary of UVA, blue light and illuminance levels during flight are shown in Figure 6-j and a summary of the illuminance UV recorder data is shown in Figure 6-k.

At the departure airport, there was overcast cloud with light rain. Take off was immediately into cloud, breaking clear of cloud at 5,000 feet at 08:06. A cloud layer remained below the aircraft throughout the flight with the exception of a short period from 08:52 to 08:56 where the surface could be seen. Descent through cloud took place between 09:50 and 10:02. Broken cloud was noted at Alicante airport on departure. The aircraft was above cloud three minutes after take-off. A cloud layer remained below though the majority of the flight. Broken cloud cover below with surface visible was noted from 12:30 to 12:45 and 13:00 to 13:10. Descent through cloud occurred from 13:47 to 13:51.

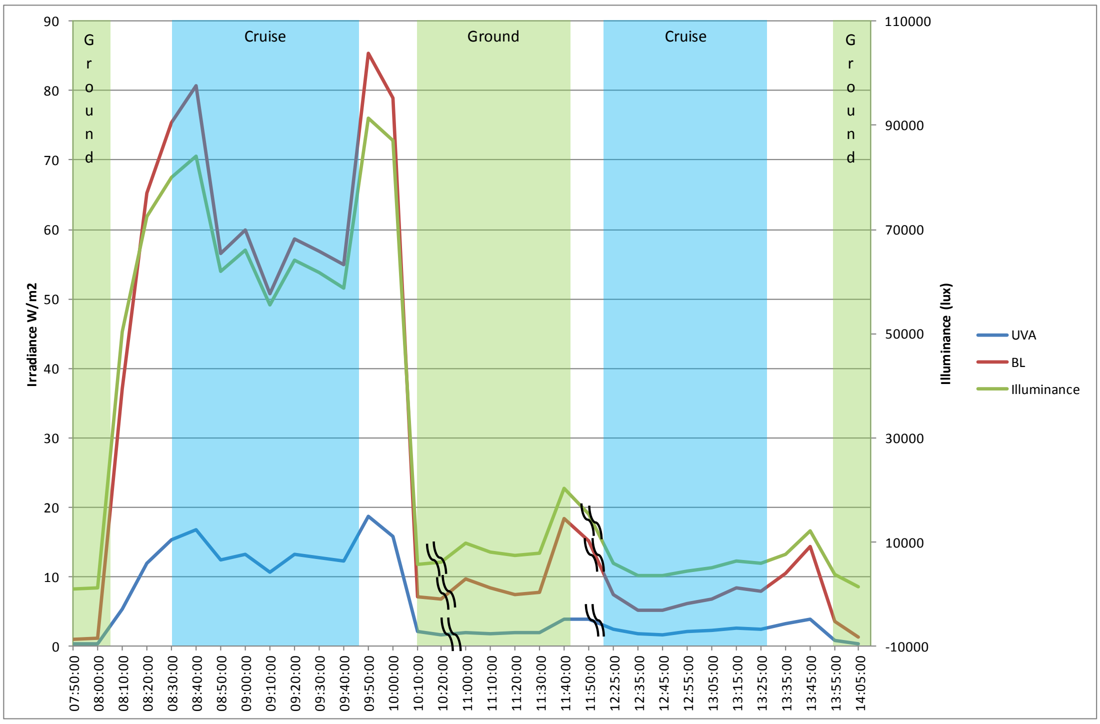

Figure 6-j Flight 5 summary of UVA, blue light and spectrometer illuminance.

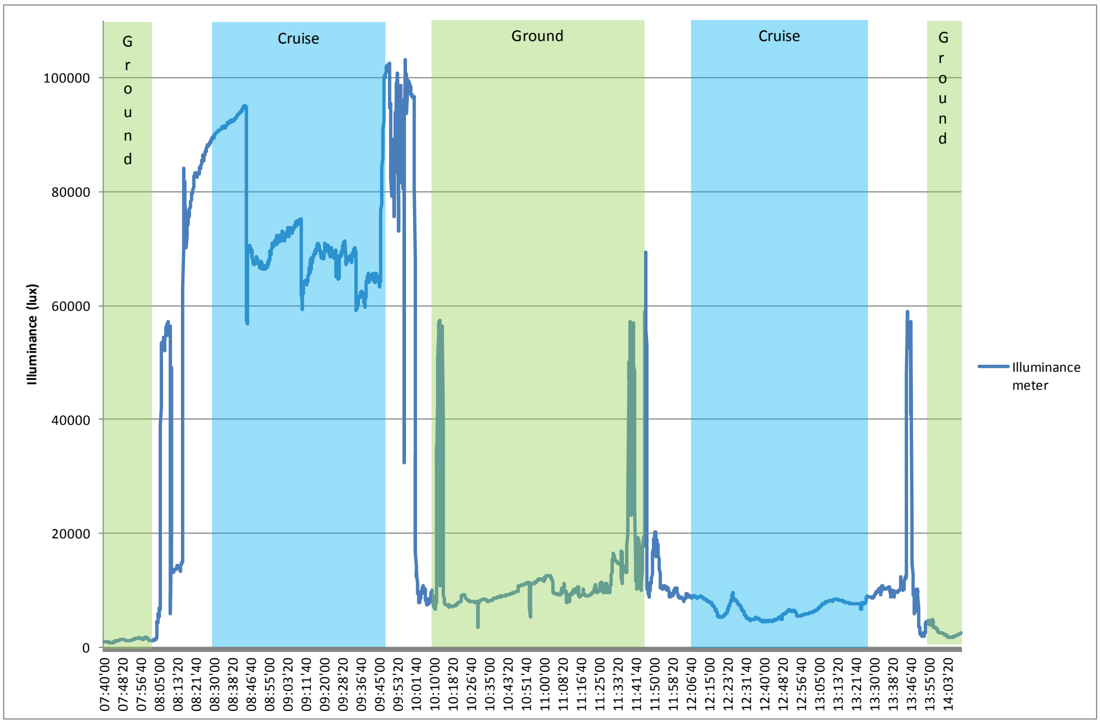

Figure 6-k Illuminance measured by illuminance UV recorder during flight 5.

Large changes in illuminance levels were seen climb and descent through cloud and during taxy where the aircraft was manoeuvring.

UVA readings peaked at 18.6 W/m^2 at 09:50. Blue light peaked at 85.4 W/m^2 also at 09:50 during descent with a cloud layer below. The total UVA radiant exposure measured by the spectrometer was 1.37 x10^5 J/m^2. The total blue light radiant exposure measured during the same period was 5.52x10^5 J/m^2. Comparing the illuminance data collected by both illuminance UV recorder and spectrometer resulted in a correction factor of 0.95. This would give revised values of 1.30 x10^5 J/m^2 for UVA and 5.24 x10^5 J/m^2 for blue light.

6.2.3.6 Flight 6 – Rhodes

A summary of UVA, blue light and illuminance levels during flight are shown in Figure 6-l.

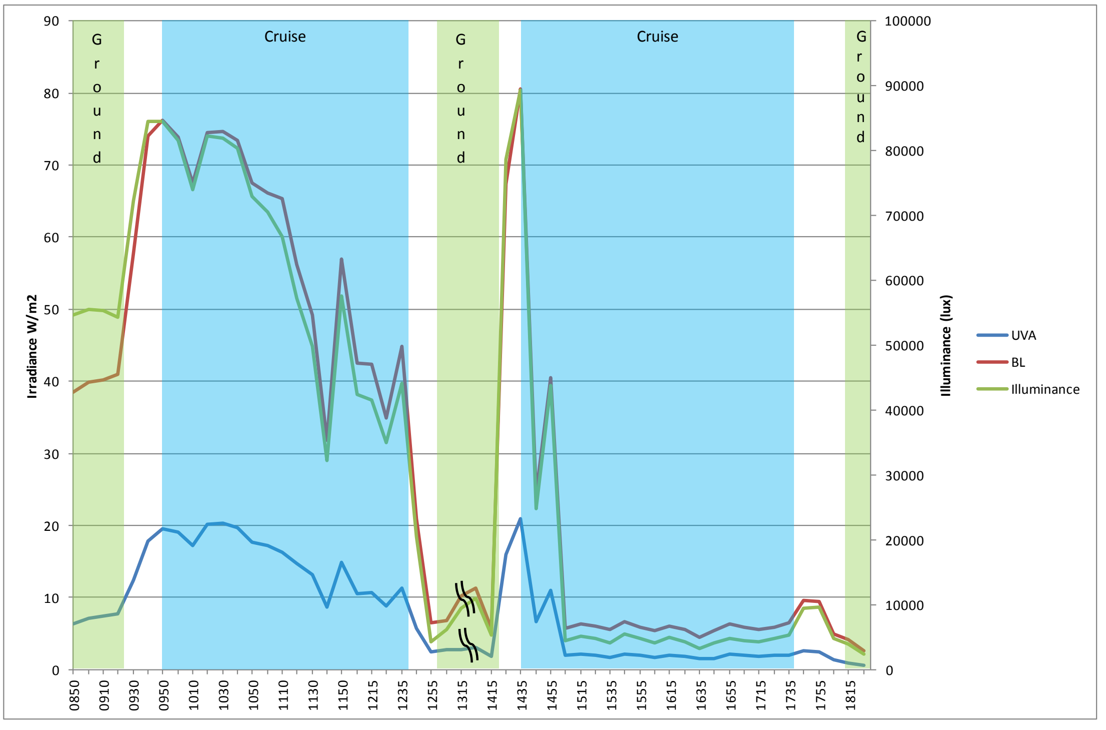

Figure 6-l Flight 6 summary of UVA, blue light and spectrometer illuminance

There was no significant cloud cover at the departure airport. From 09:38 throughout the outbound sector, a thin light cloud cover or haze was noted well below cruise altitude. Conditions were also clear at Rhodes during turn around and for departure. From five minutes after take-off, haze was again noted intermittently.

By 15:10, a thick cloud layer was noted below the aircraft. Between 17:29 and 17:36, there was reduced visibility ahead. Descent through cloud occurred between 17:37 and 17:45 after which surface was visible and aircraft was clear of cloud for the remainder of the flight.

A summary of the illuminance UV recorder data is shown in Figure 6-m. Large fluctuations in illuminance during turn around at Rhodes correspond to the equipment being moved in order to carry out a series of ground windshield transmittance measurements (chapter 8).

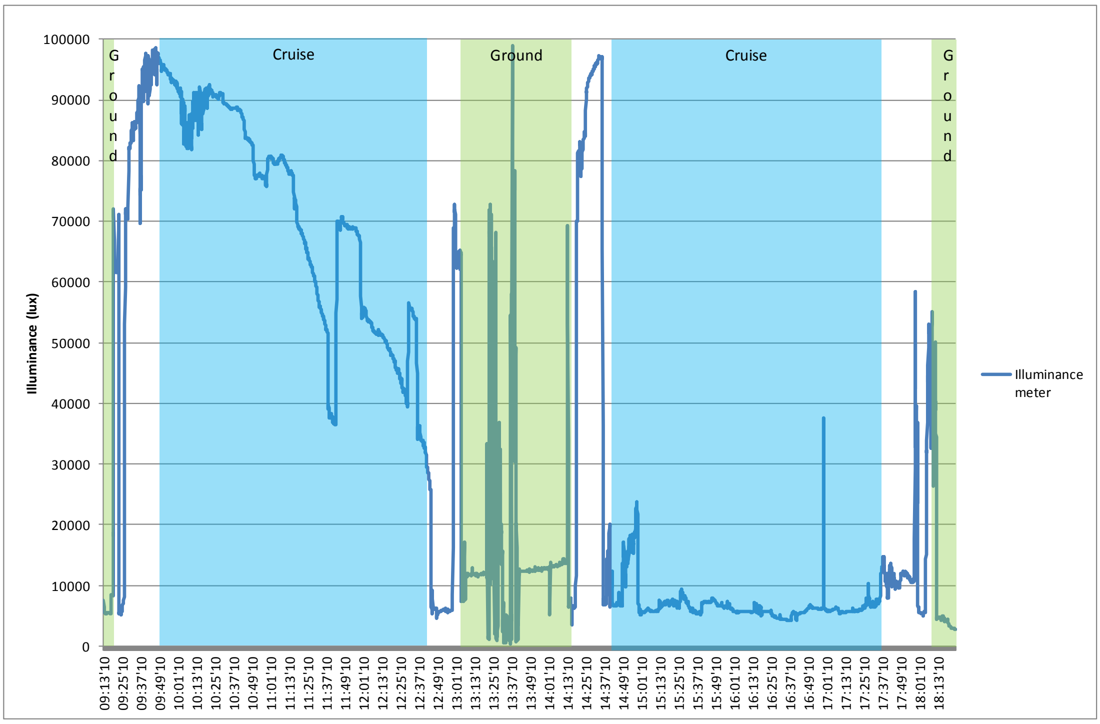

Figure 6-m Illuminance measured by illuminance UV recorder during flight 6.

UVA readings peaked at 20.9 W/m^2 at 14:35. Blue light peaked at 80.5 W/m^2 also at 14:35 having just reached cruise altitude on the inbound sector. The total UVA radiant exposure measured by the spectrometer was 2.25 x10^5 J/m^2. The total blue light radiant exposure measured during the same period was 8.81 x10^5 J/m^2. Comparing the illuminance data collected by both illuminance UV recorder and spectrometer (which excludes the ground data at turnaround) resulted in a correction factor of 1.21. This would give revised values of 2.72 x10^5 J/m^2 for UVA and 1.07 x10^6 J/m^2 for blue light.

6.2.4 Aeroplane azimuth flight plots

An azimuth-elevation plot as described in section 1.4.4.4 has been modified to show the approximate position of the sun in relation to the pilot for each flight sector. The relative solar positions at start and end of flight are plotted. These data were calculated using an on-line sun position calculator (Honsberg and Bowden, no date b) which takes into account the Universal Co-ordinated Time (UTC) and the longitude and latitude of reference position. As no GPS data were available, the airport co-ordinates are used. The start and end positions are joined and an arrow indicates the direction of change of relative position of the sun during flight.

Using the binocular visibility plots from Airbus manuals (Airbus, 2012; Airbus, 2014), an approximation of the area in which sunlight could be directly viewed by the pilot through the aircraft windows is plotted. This has been calculated as the vertical angle from the horizontal 'eyes ahead' plane. This plane is taken as a reference point and coincides with the outermost circle on the azimuth-elevation plot representing the horizon (0°). The solid line represents the boundaries of direct sunlight view from the captain's seat whilst the broken line represents the boundaries of direct sunlight view from the first officer's seat. Whilst the areas are the same size, it can be seen that direct sunlight may be directly visible to only one of the pilots.

The straight line bearing between departure and destination airports was calculated using an on-line calculator (SunEarthTools, no date) using the longitude and latitude co-ordinates of each airport.

The plots represent an approximation of the relative solar position during flight and are used to offer supporting explanation for the differences in irradiation measured during flight. The accuracy of the azimuth flight plots may be affected by a number of factors including:

1) A constant heading is used which represents a direct track between airports. In reality, a number of heading changes are usually made during flight as the aircraft traverses along airways using a series of ground navigation aids (see section 1.5.2). Additionally, depending on wind direction and speed, the aircraft may adopt a particular heading in order to maintain a desired track. The direction in which the aircraft points affects the azimuth flight plots. The track angle used has been rounded to the nearest 5°.
2) As there is no time stamped in-flight GPS data available, only start (take off) and finish (landing) times are available as reference points for relative solar

position. Therefore, a relative solar position at a particular point during flight can only be estimated from likely solar path and the proportion of total flight time elapsed.

3) The binocular visibility data from the Airbus A320 series has been used as this aircraft was flown most frequently in this study (for flights 1,2,3 and 5). Additionally, the A320 graphs also include angular data from the opposite window which are not available in the Airbus A330 data. Although the extent of angle subtended at the eye for the front windshield are similar between A320 and A330 series, the areas plotted may not be accurate for other aircraft types.
4) The area of binocular visibility plotted represents the maximum extent and includes eye and head movement. As a pilot's attention is generally directed ahead, a view of the solar disc through a rear side window will have less effect on ocular irradiance than if present through the front windshield. Indeed, a relative solar position ahead of the aircraft but above the field of view limited by the top of the front windshield is likely to affect ocular exposure more than a relative solar position giving a direct view of the sun from a side window.
5) The area of visibility does not take into account windshield frame structure (which could cause a block of the solar disc area) or the use of visors (which would attenuate irradiance from the solar disc area).

Figure 6-n and Figure 6-o show the azimuth flight plots for flight 1 outbound and inbound respectively.

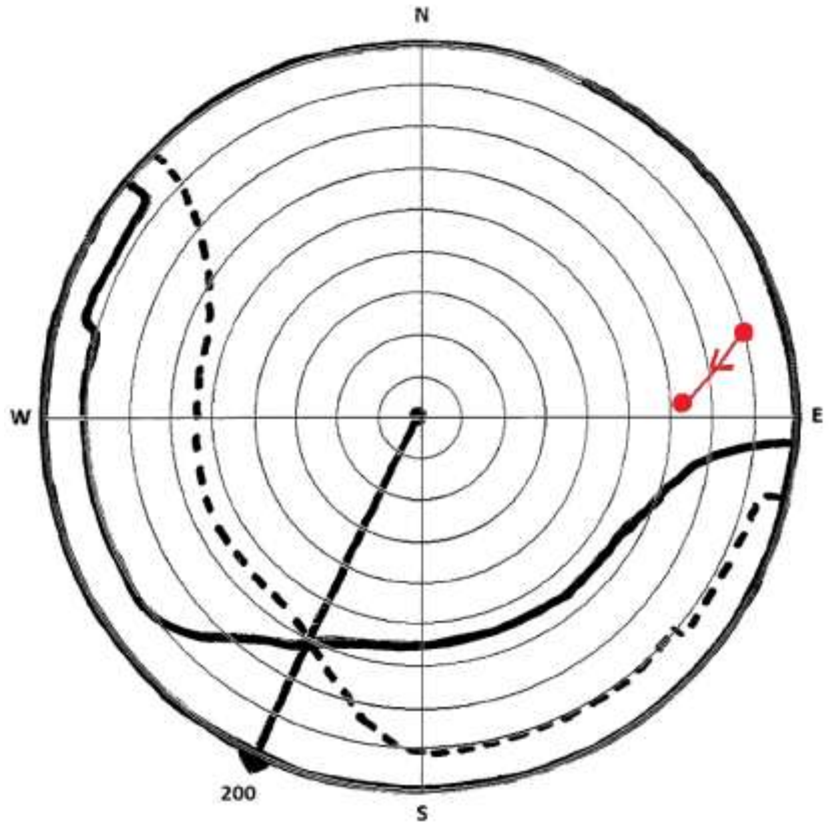

Figure 6-n Azimuth plot for flight 1 outbound.

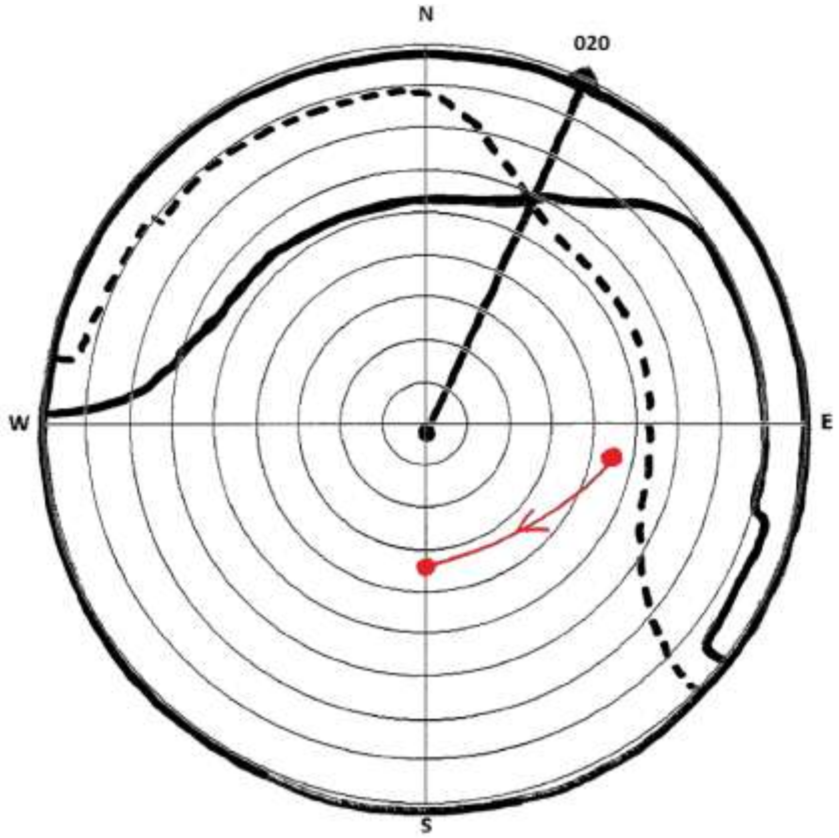

Figure 6-o Azimuth plot for flight 1 inbound.

The spectrometer probe during this flight was placed near the front windshield on the captain's side (left) of the cockpit. Comparing outbound and inbound sectors, irradiance levels measured were not seen to be markedly different. Both cruise sectors correspond with a relative solar position outside direct line of sight.

The same azimuth flight plot is presented for flights 2 and 3 as the destination was the same and flight date and timings were similar (6 days apart and departure and arrival times within 30 minutes). Figure 6-p and Figure 6-q show the azimuth flight plots valid for these outbound and inbound flights respectively.

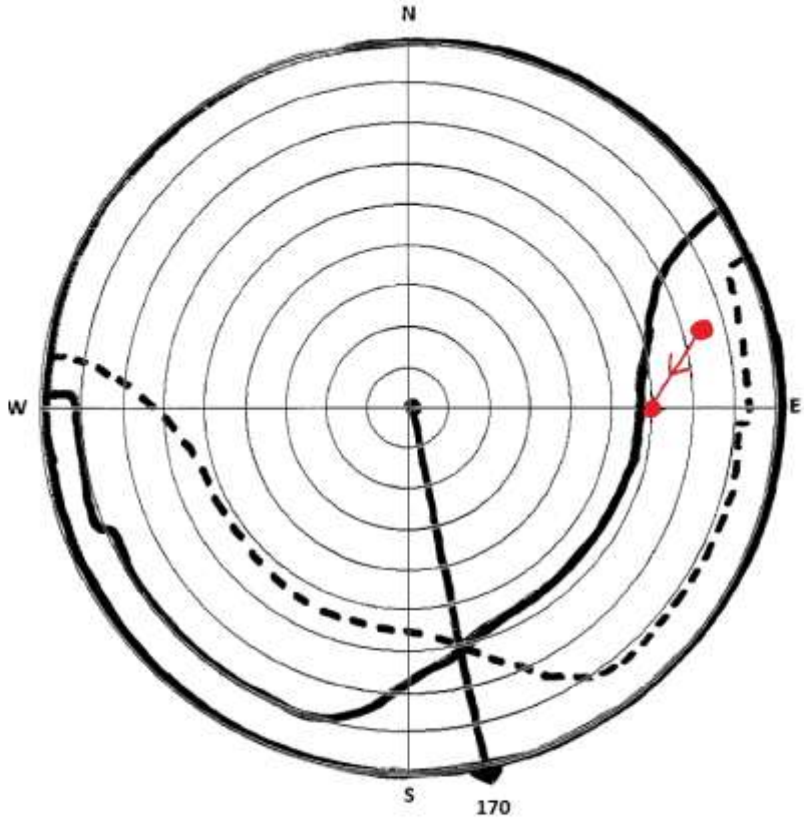

Figure 6-p Azimuth flight plot for flights 2 and 3 outbound

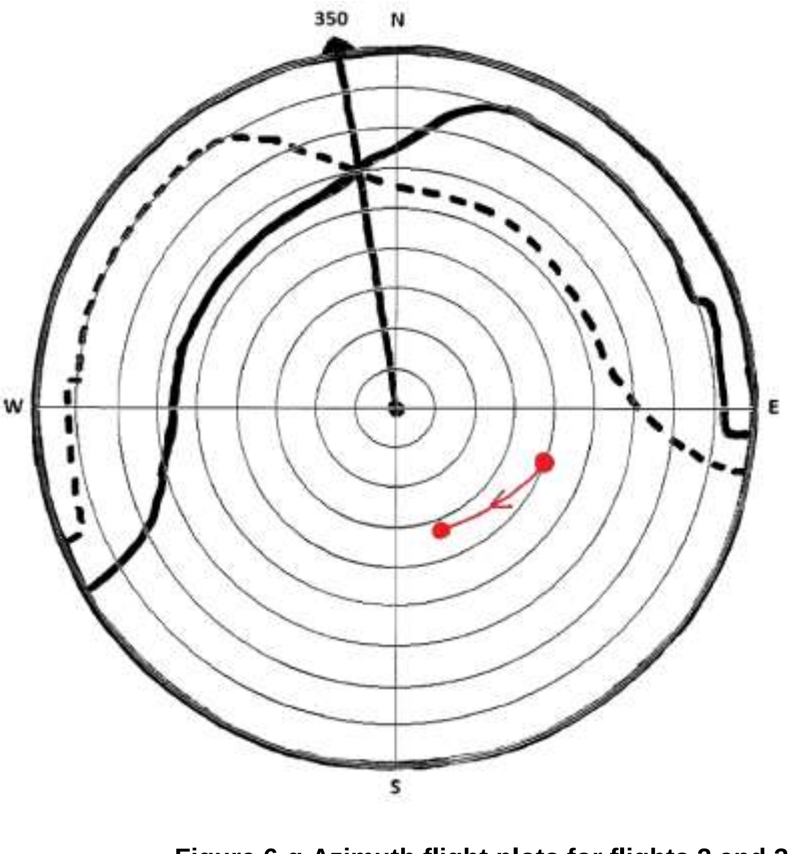

Figure 6-q Azimuth flight plots for flights 2 and 3 inbound

The spectrometer probe was again placed on the captain's side for both flights. Direct sunlight may have been visible to the captain beyond 90° to the left on the outbound flight. As discussed, this is unlikely to have caused a significant increase in ocular exposure but may offer an explanation for the gradual increase in irradiance seen over the outbound cruise (Figure 6-d and Figure 6-g).

The azimuth flight plot for flight 4 is shown in Figure 6-r. The probe was placed on the first officer's (right) side during flight.

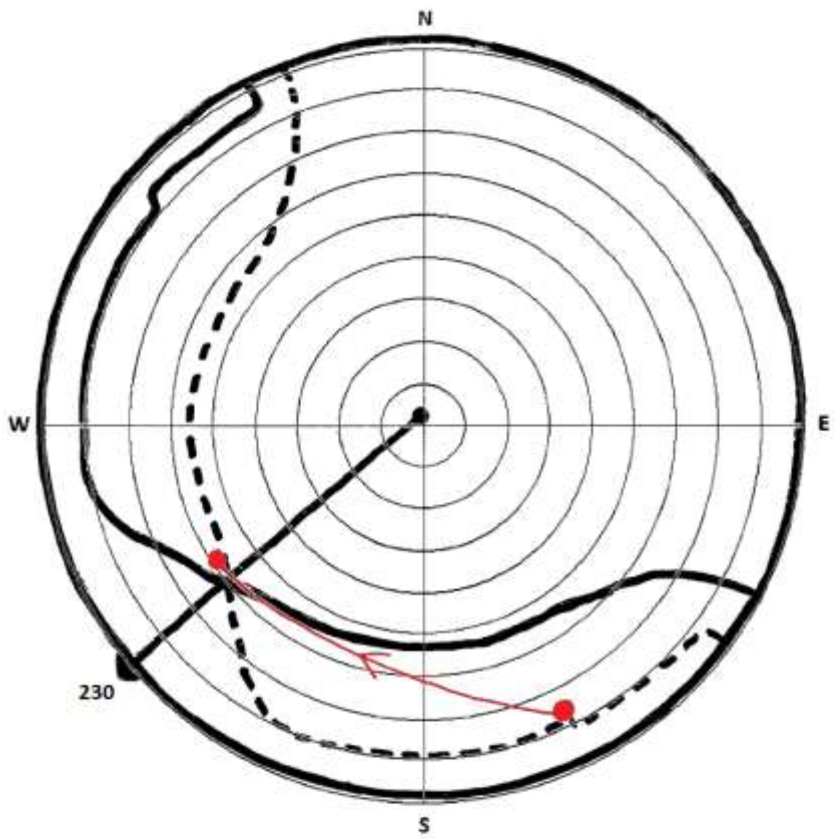

Figure 6-r Azimuth flight plot for flight 4

The solar disc can be seen to be potentially within the captain's direct view (allowing for head turning) during flight. It also becomes progressively nearer the direction of travel of the aircraft. This would offer an explanation as to the overall gradual increase in irradiance seen during this flight (Figure 6-h, p.157).

The azimuth flight plots for flight 5 are shown in Figure 6-s (outbound) and Figure 6-t (inbound).

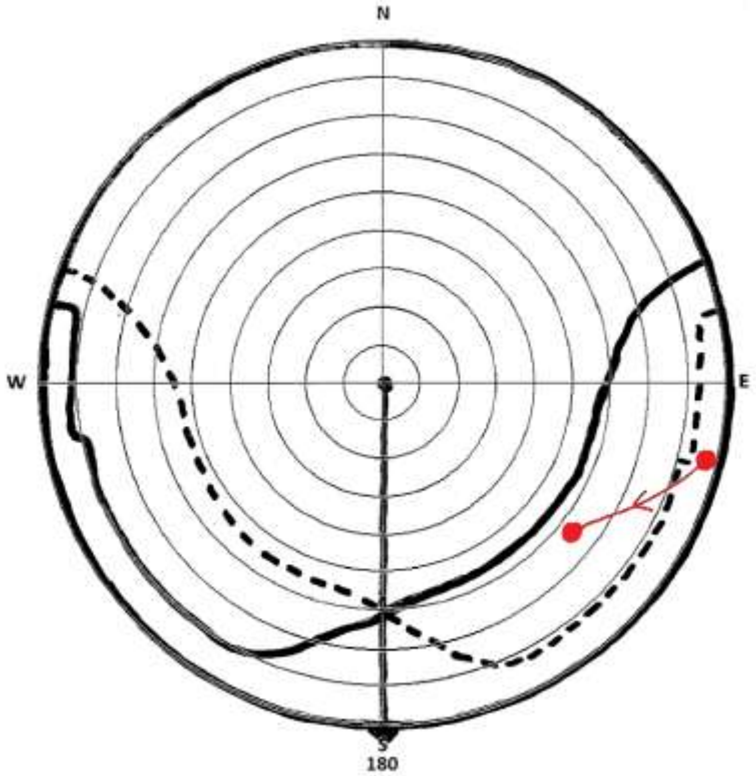

Figure 6-s Azimuth flight plot for flight 5 outbound.

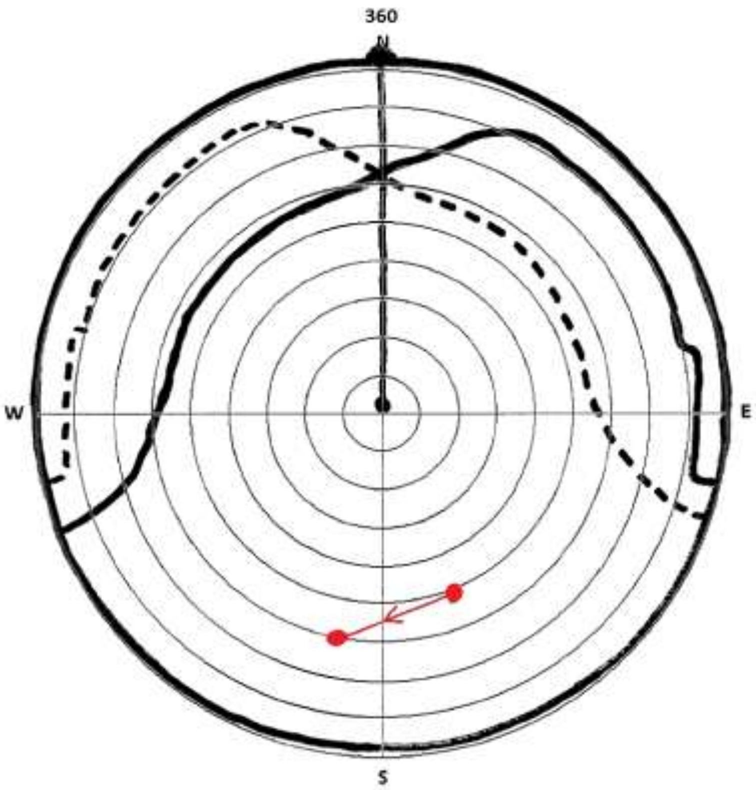

Figure 6-t Azimuth flight plot for flight 5 inbound.

The spectrometer probe was positioned at the left hand front windshield. It can be seen that the solar disc is likely to be visible (allowing head and eye rotation) at the captain's eye position throughout the outbound flight whereas on the inbound flight, the relative solar position is well away from the line of sight and direction of travel of the aircraft. Correspondingly, irradiance levels seen are significantly higher during the outbound sector (Figure 6-j).

Azimuth flight plots for flight 6 are shown in Figure 6-u (outbound) and Figure 6-v (inbound) respectively.

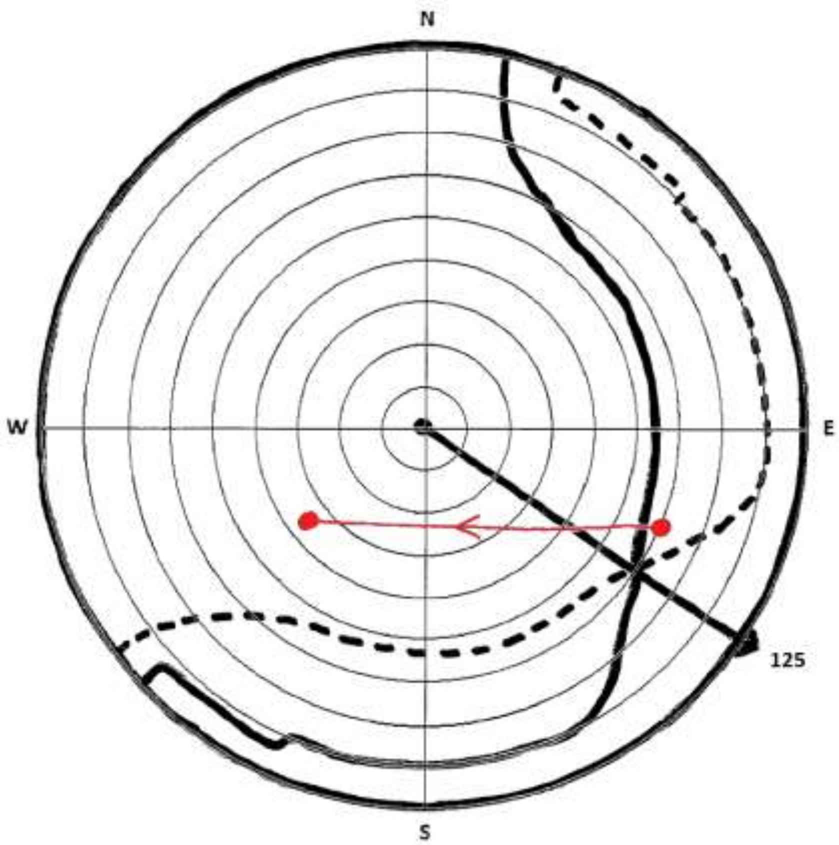

Figure 6-u Azimuth flight plot for flight 6 outbound.

The spectrometer probe was positioned at the left hand window for the duration of the flight. Irradiance levels were significant higher during the oubound flight where the relative solar position was close to the direction of travel. During the outbound sector, irradiance levels decreased which corresponds to the elevation angle increased above the direct windshield view. Although decreasing, it remained higher at the spectrometer which was positioned closer to the windshield and would have a larger vertical field of view compared to the pilot's eyes. Additionally, this is seen by a significantly lower ratio of measurements between manual and fixed illuminance UV recorders during the outbound cruise. The mean ratio for 'eyes ahead' to fixed position over this sector was 0.09. A similar mean ratio for flights 1,2 and 3 was between 0.46 to 0.61. A lower and relatively constant level of irradiance was measured during the inbound sector. This corresponded with an off axis relative solar position of around 45° and a smaller relative positional change throughout the inbound flight.

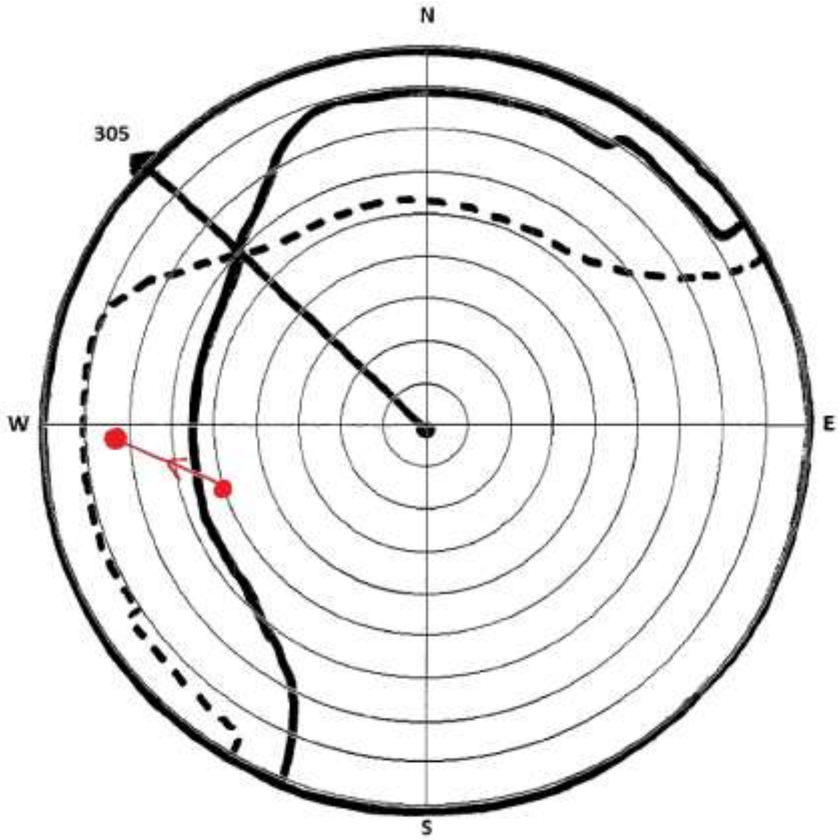

Figure 6-v Azimuth flight plot for flight 6 inbound.

6.2.5 Aeroplane flight measurements summary

For all aeroplane flights, the mean UVA signal was 2.4 times higher at cruise altitude compared to the signal at ground level. The mean blue light hazard signal was 4.1 times higher at altitude and average illuminance levels were 3.8 times higher at altitude compared to ground level. These values were calculated by using the mean altitude signal for all aeroplane flights compared to the mean ground signal for all aeroplane flights. The ground to altitude increase varied for each individual flight (from between 1.2 and 29.5 for blue light weighted radiance). The highest increase signal measured during flight 4 (Tobago) which was due partly to the bright conditions and relative solar position during flight, but also to the low ground signal at departure due to weather conditions and time of year. Each flight had fewer ground measurements captured than at altitude and a larger variation was seen in these ground measurements. This was partly due to the difference in weather conditions, latitude and time of day between departure and destination airports, and also due to the often large changes to illuminance as the aircraft manoeuvres from the stand to the runway threshold. These variations in illuminance measured during taxy can be seen from the illuminance UV recorder graphs in section 6.2.3. Similar calculations were conducted for helicopter flights described in chapter 6.2.13.

UVA readings were significantly lower on flights 3 (Barcelona) and 4 (Tobago). Data were generally consistent during stable cruise with the greatest variations seen during the following phases of flight:

1) Descent and approach to land. The aircraft is reducing in altitude and will commonly pass through lower altitude cloud during descent. The aircraft will adopt a more nose down attitude. Multiple changes of heading and airspeed are usually required before the aircraft is established on final approach. Large variation in illuminance is due to changes to the relative position of the sun to the spectrometer. The effect of reflection from cloud top is likely to be greater where the aircraft is at a lower altitude above cloud tops than at cruise altitude. Additionally, there is likely to be a large change in cockpit illuminance between flying just above cloud tops with both direct and reflected sunlight being present, to flying just below cloud base with diffuse sunlight only.

2) Initial climb after take-off. The aircraft in this phase of flight will be at a significantly nose up attitude. The relative position of the sun to the spectrometer will consequently be lower and nearer the line of sight. Additionally, large increases in illuminance are likely to be found when climbing through and above cloud, as described above.

3) Taxy. Large changes of heading are likely to be required in order for the aircraft to move from the stand to the runway threshold. This will cause large changes to the relative position of the sun. Additionally, sunlight reflection from taxiway and runway surfaces (particularly if wet) may increase cockpit illuminance further.

6.2.6 Aeroplane hazard ratios

A summary of UVA hazard ratios are shown in Figure 6-w. The UVA hazard ratio is expressed as the un-weighted UVA divided by the illuminance for each reading (European Commission, 2006).

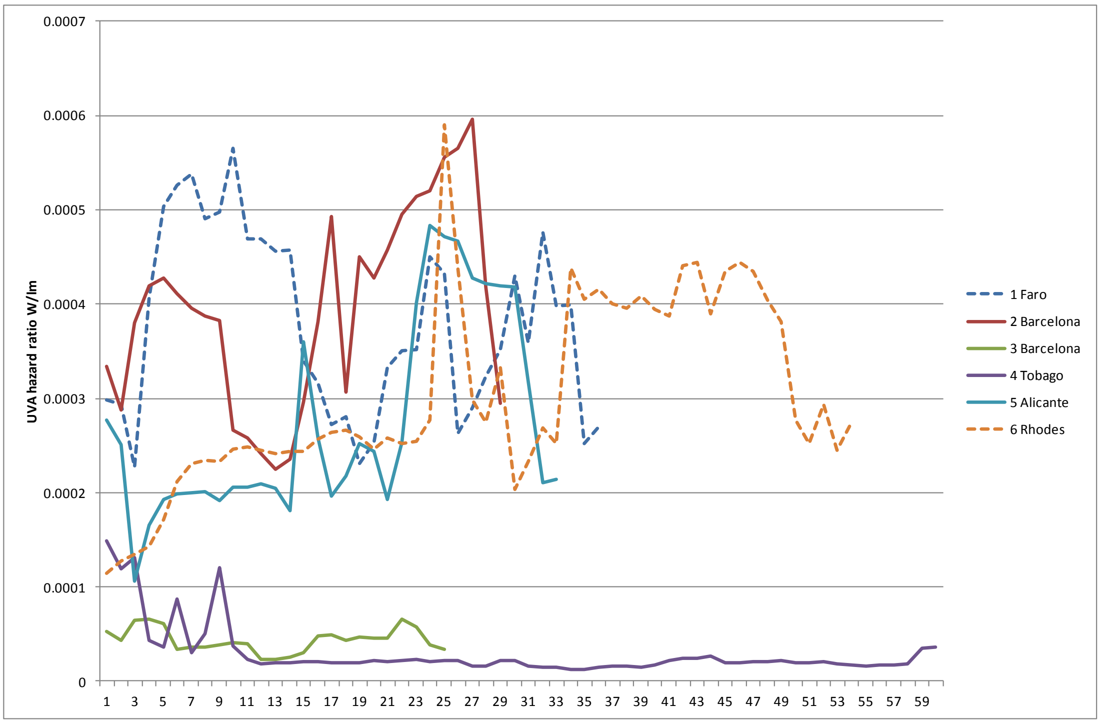

Figure 6-w Calculated UVA hazard ratios throughout flight; x axis represents number of spectrometer readings taken.

Each flight is represented with consecutive spectrometer readings plotted. These were generally captured at 10 minute intervals except during turn-around where the equipment was not recording for a period of time. The horizontal axis is therefore not time comparable between flights. With the exception of flight 4 which was a one sector flight, outbound flights constitute approximately the first half of the total number of readings and the inbound flight represents the remaining readings for that particular flight.

It can be seen that flights 3 (Barcelona) and 4 (Tobago) have low UVA hazard ratio which is due to the superior UV attenuating properties of the front windshields installed on those aircraft (see section 6.3.5). Flights 5 (Alicante) and 6 (Rhodes) show lower hazard ratios on outbound sectors compared to inbound sectors. Flight 1 (Faro) shows a higher hazard ratio on the outbound sector.

Blue light hazard ratios were calculated by dividing each weighted blue light measurement with illuminance and are shown in the same format in Figure 6-x.

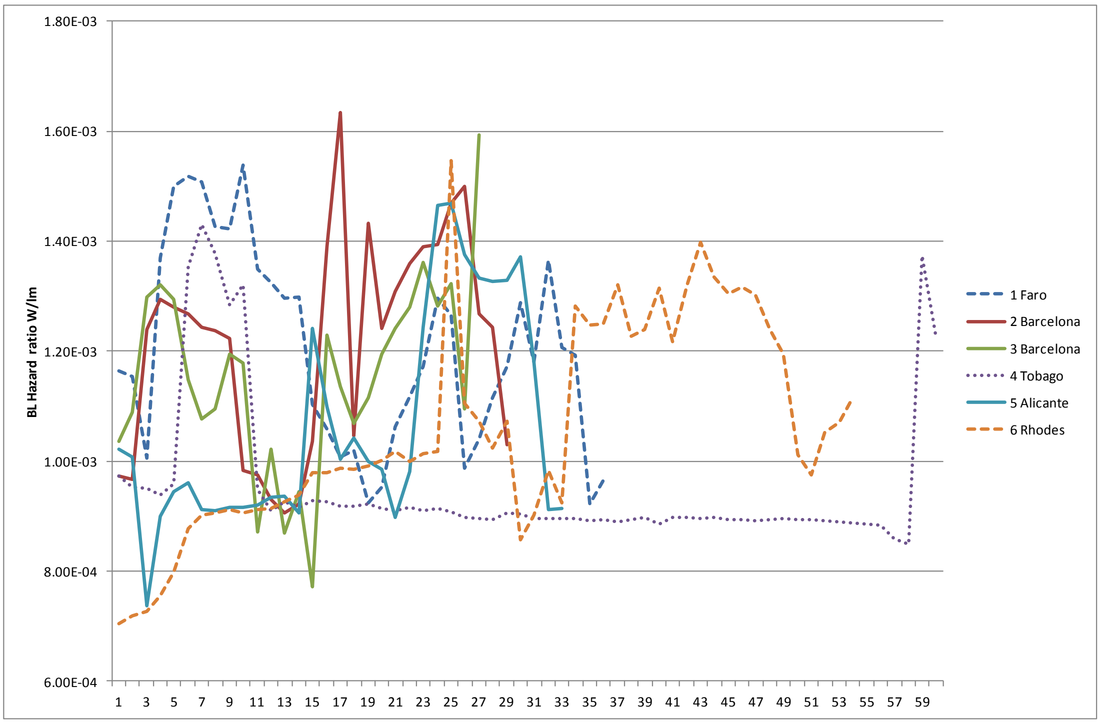

Figure 6-x Blue light hazard ratios throughout flight; x axis represents the number of spectrometer reading taken.

The Barcelona flights (2 and 3), carried out at a similar time of year, show similar hazard ratio profiles. As with UVA hazard ratios, flights 5 (Alicante) and 6 (Rhodes) show lower hazard ratios on outbound sectors compared to inbound sectors. Again, flight 1 (Faro) shows a higher hazard ratio on the outbound sector.

6.2.7 Aeroplane ocular exposure to UV

A summary of UVA dose calculated for each flight is shown in Table 6-f. A proportion of the visual flying task is directed toward instruments whilst there is also a proportion of the visual task which would be directed ahead looking through the front aircraft windshield. Therefore, 'down' and 'ahead' should be considered the minimum and maximum ocular exposure respectively. For each flight of two sectors, a value has been calculated, based on illuminance meter and spectrometer data for the exposure during turn around where the aircraft is in a stationary position.

The values shown are expressed in both dose (J/m^2) and as a proportion relative to the daily UVA exposure limit (10,000 J/m^2) recommended under ICNIRP guidelines.

Flight	UVA dose				Flight duration (min)	UVA dose including turn around			
	UVA ahead, J/m^2	Relative to ICNIRP guidelines	UVA down, J/m^2	Relative to ICNIRP guidelines		UVA ahead, J/m^2	Relative to ICNIRP guidelines	UVA down, J/m^2	Relative to ICNIRP guidelines
1 Faro	23405	2.34	11804	1.18	290	30400	3.04	15286	1.53
2 Barcelona	17051	1.70	10320	1.03	206	19591	1.96	12249	1.22
3 Barcelona	1468	0.15	771	0.08	204	1641	0.16	910	0.09
4 Tobago	2167	0.22	1700	0.17	588	N/A		N/A	
5 Alicante	38158	3.82	26705	2.67	301	39393	3.94	27693	2.77
6 Rhodes	62395	6.24	42129	4.21	479	65630	6.56	45481	4.55

Table 6-f Summary of UVA dose compared to ICNIRP limits both with and without destination turnaround time.

During flight 5, it was calculated that the ICNIRP guideline limit was exceeded within 1 hour after takeoff from London Gatwick assuming an eyes down position or in less than 30 minutes after takeoff assuming an eyes ahead position. This also assumes that the pilot had no UV eye protection in place. The mean ocular UVA dose per hour is shown in Table 6-g for each flight for both eyes ahead and eyes down towards instrument position.

Flight	UVA per hour J/m^2 (ahead)	UVA per hour J/m^2 (down)
1 Faro	4842	2442
2 Barcelona	4966	3006
3 Barcelona	432	227
4 Tobago	221	173
5 Alicante	7606	5323
6 Rhodes	7816	5277

Table 6-g Summary of ocular UVA dose per hour for each flight.

6.2.8 Aeroplane ocular exposure to blue light hazard

Using the manual illuminance UV recorder data collected during flight and spectral irradiance measured at windshield, the blue light weighted effective radiance was calculated for both 'eyes ahead' and 'eyes down'. The minimum, maximum, mean and standard deviations for each flight are shown for both eyes ahead (Table 6-h) and eyes down (Table 6-i) positions.

Maximum radiance to prevent type II damage = $100W/m^2.sr$						Maximum radiance dose over 10,000 sec to prevent type II damage = $1x10^6$	
Flight	Mean Radiance $W/m^2.sr$	Standard deviation	Min Radiance $W/m^2.sr$	Max Radiance $W/m^2.sr$	Flight duration (min)	Radiance dose for flight ($J/m^2.sr$)	Relative to ICNIRP guidelines
1 Faro	5.87	1.58	3.74	11.28	290	60991	0.06
2 Barcelona	5.95	3.11	0.86	13.75	206	79974	0.08
3 Barcelona	4.34	1.57	0.75	7.05	204	50597	0.05
4 Tobago	3.5	4.73	0.18	32.06	588	58611	0.06
5 Alicante	13.31	20.71	0.19	94.81	301	245122	0.25
6 Rhodes	9.87	20.90	0.25	115.86	479	193783	0.19

Table 6-h Summary of blue light hazard radiance for an eyes ahead position.

Maximum radiance to prevent type II damage = $100W/m^2.sr$						Maximum radiance dose over 10,000 sec to prevent type II damage = $1x10^6$	
Flight	Mean Radiance $W/m^2.sr$	Standard deviation	Min Radiance $W/m^2.sr$	Max Radiance $W/m^2.sr$	Flight duration (min)	Radiance dose for flight ($J/m^2.sr$)	Relative to ICNIRP guidelines
1 Faro	2.98	0.93	0.99	4.70	290	30820	0.03
2 Barcelona	3.65	2.22	0.72	9.43	206	53547	0.05
3 Barcelona	2.29	1.14	0.55	4.77	204	30600	0.03
4 Tobago	2.75	4.13	0.12	21.28	588	36239	0.04
5 Alicante	9.32	14.37	0.17	53.84	301	183271	0.18
6 Rhodes	6.65	10.51	0.17	52.53	479	113783	0.11

Table 6-i Summary of blue light hazard radiance for an eyes down position.

It can be seen that throughout flights 1-5, the maximum blue light weighted radiance calculated was within the $100W/m^2.sr$ limit on an assumption that such an exposure would continue. The effective radiance dose for these flights would fall well within the 1×10^6 $J/m^2.sr$ limit over 10,000 seconds and there is no evidence of a risk of type II photochemical retinal damage occurring during these flights.

Flight 6 showed two readings to be beyond the $100W/m^2.sr$ radiance limit. These occurred around 1710-1715 (UTC+1) during the latter stages of cruise on the inbound sector. These values were affected largely as the illuminance reading from the manual illuminance UV recorder was significantly higher than its corresponding twin unit by the spectrometer. Assessing the azimuth flight plot (section 6.2.4), this occurred while the solar disc was likely to be directly visible from the captain's eye position and at a relative angle of approximately 45° left of heading. The most likely explanation was that during this short period of time, direct sunlight through the side window was affecting manual readings to a greater extent than the spectrometer readings. Excluding these two readings, the highest remaining radiance reading during this flight was 20.8 $W/m^2.sr$.

Effective radiance dose for flight 6 was calculated which showed a maximum calculated dose of 1.94×10^5 $J/m^2.sr$ over a 10,000 second period. This is the equivalent of 0.19 of the radiance dose limit as stated in ICNIRP.

6.2.9 Aeroplane ocular illuminance data

A summary of the average illuminance measured by both illuminance UV recorder and spectrometer is shown in Table 6-j.

Flight	**Av illum. Ahead (lux)**	**Av illum. down (lux)**	**Av illum at spectrometer (lux)**
1 Faro	4406	2291	5798
2 Barcelona	4200	2600	5262
3 Barcelona	5704	3309	7198
4 Tobago	2367	1983	65654
5 Alicante	10666	7387	29576
6 Rhodes	7338	5038	33845

Table 6-j Summary of mean illuminance during flight as measured by spectrometer and manual illuminance UV meter.

It can be seen that on flight 4 (Tobago), the average spectrometer illuminance was highest, yet average illuminance at the eye position was lowest. This is discussed further in section 6.3.6.

As with the spectrometer data, illuminance readings taken at pilot eye level varied throughout flight. Minimum and maximum values recorded on each flight are shown inTable 6-k.

Flight	Min illum. Ahead (lux)	Max illum ahead (lux)	Min illum. down (lux)	Max illum down (lux)
1 Faro	2900 (clb)	12000 (desc)	1300 (clb)	5000 (desc)
2 Barcelona	900 (grd)	10500 (alt)	760 (grd)	6900 (alt)
3 Barcelona	1500 (grd)	61500 (clb)	1200 (grd)	39000 (clb)
4 Tobago	142 (grd)	6200 (desc)	97 (grd)	4000 (desc)
5 Alicante	165 (grd)	81000 (alt)	149 (grd)	46000 (alt)
6 Rhodes	750 (grd)	80000 (alt)	600 (grd)	39000 (alt)

Table 6-k Summary of minimum and maximum manual illuminance readings. The phase of flight where the readings were taken is shown in brackets: grd = ground, clb = climb, alt = altitude cruise, desc = descent. All maximum and minimum readings for each flight occurred on the same timed measurement. Note that no ground illuminance readings were taken on flight 1 (faro).

6.2.10 Aeroplane erythemal weighted irradiance

Erythemal weighted function (section 1.4.8) was included in the data analysis (Table 6-l). From the data, erythemal weighted irradiance was calculated for each spectral measurement. The total erythemal UV dose (J/m^2) was then calculated for each sector. Standard Erythemal Dose (SED) is an erythemally weighted measure of radiant exposure and is equivalent to 100 J/m^2. Erythema doses are insignificant for all flights.

Flight	SED per flight	SED/hr
1 (a)	0.071	0.04
1 (b)	0.131	0.06
2 (a)	0.076	0.05
2 (b)	0.277	0.08
3 (a)	0.037	0.01
3 (b)	0.109	0.07
4	3.459	0.36
5(a)	1.226	0.63
5 (b)	0.454	0.18
6 (a)	1.193	0.30
6 (b)	0.346	0.08

Table 6-l Summary of calculated SED per flight and per hour.

These values are higher than the anticipated SED that the pilot would receive. The arms, hands and head of the pilot would be further back inside the cockpit and would not be expected to receive as high a signal as the spectrometer situated just behind the windshield. In order to calculate the expected dose at the pilot's face, the average ratio on each flight of the paired timed readings between the illuminance UV meter at the spectrometer and the manual illuminance UV meter readings taken at eye position looking ahead was calculated (Table 6-m). This is likely to represent the lower limit of erythema dose as the pilot's arms and hands are likely to be in a forward position and nearer the windshield relative to the head. The average calculated SED over all aeroplane flights was 0.06 SED/hr.

Flight	**SED per flight**	**SED/hr**
1 (a)	0.051	0.03
1 (b)	0.070	0.03
2 (a)	0.046	0.03
2 (b)	0.130	0.04
3 (a)	0.020	0.01
3 (b)	0.043	0.03
4	0.361	0.04
5(a)	0.355	0.18
5 (b)	0.229	0.09
6 (a)	0.105	0.03
6 (b)	0.548	0.13

Table 6-m Summary of calculated SED at the pilot's face using ahead position illuminance UV meter data.

6.2.11 Effect of time of year

Flights 2 and 3 to Barcelona were conducted on 22 and 26 May respectively. Flight 5 to Alicante was conducted on 1 March. The route along airways passed within 80 miles of Barcelona airport. Data from the Barcelona flight collected from take off at London Gatwick to the start of descent toward Barcelona was compared to data from the Alicante flight from take off at London Gatwick for the same length of time. Due to the transmittance properties of the windshields (section 6.3.5), flights 2 and 5 were compared. Spectrometer data from flight 5 showed the average illuminance to be 11.9 times higher than flight 2. UVA was 5.6 times higher and blue light was 9.0 times higher than flight 2. This large difference is likely to be due to the presence of a significant cloud layer below the aircraft on flight 5 (section 6.2.3.5) together with a lower elevation angle and different azimuth angle (section 6.2.4).

6.2.12 Helicopter spectrometer data

A summary of the data files collected during helicopter flights are given in Table 6-n. As before, each complete spectrum was a result of six measurements: a spectral and dark measurement for each of the three regions. There were no saturated spectra. Dark spectra measured under standardised conditions described in section 6.2.21.2 were applied in cases of shutter failure.

Flight	No of complete spectra	No of saturated spectra	No of spectra with non-operational shutter	No of spectra requiring stitching
7 (a+b)	17	0	0	0
8 (a+b)	13	0	5	2
9 (a+b)	17	0	0	1
10 (a+b)	19	0	9	0

Table 6-n Summary of the spectrometer data measurements for helicopter flights together with the number of saturated readings (discarded), number of reading where the shutter was not functional and the number of spectra requiring stitching.

Stitching was carried out for three spectra. Stitching was generally only required in cases where the spectrometer was capturing data during fast changing conditions such as climb or descent through cloud. A number of spectra could not be stitched in the UV range during flights 9 and 10 where the ASAS did not save a region 3 data file. This occurred on one occasion during flight 9 and on 14 spectral acquisitions on flight 10.

6.2.13 Helicopter UV, blue light and illuminance data

6.2.13.1 Flight 7

A summary of UVA, blue light and illuminance levels during flight are shown in Figure 6-y. No weather observations were recorded during this flight as it was not possible for the researcher to be on board. Flight details were obtained from the aircraft after flight including take off and landing times, altitudes and headings. A summary of illuminance measurements from both spectrometer and illuminance UV recorder are shown in Figure 6-z.

Sharp spikes in illuminance were seen immediately after take-off from Claymore A and at the start of the approach toward Aberdeen airport. Both UVA and blue light readings peaked at 12:20 during inbound cruise at around 1,000ft. Readings were 5.3 W/m^2 and 13.9 W/m^2 respectively. The total UVA radiant exposure measured by the spectrometer was 4.72 $x10^4$ J/m^2. The total blue light radiant exposure measured during the same period was 1.26 $x10^5$ J/m^2. Comparing the illuminance data collected by both illuminance UV recorder and spectrometer resulted in a correction factor of 1.41. This would give revised values of 6.66 $x10^4$ J/m^2 for UVA and 1.77 $x10^5$ J/m^2 for blue light.

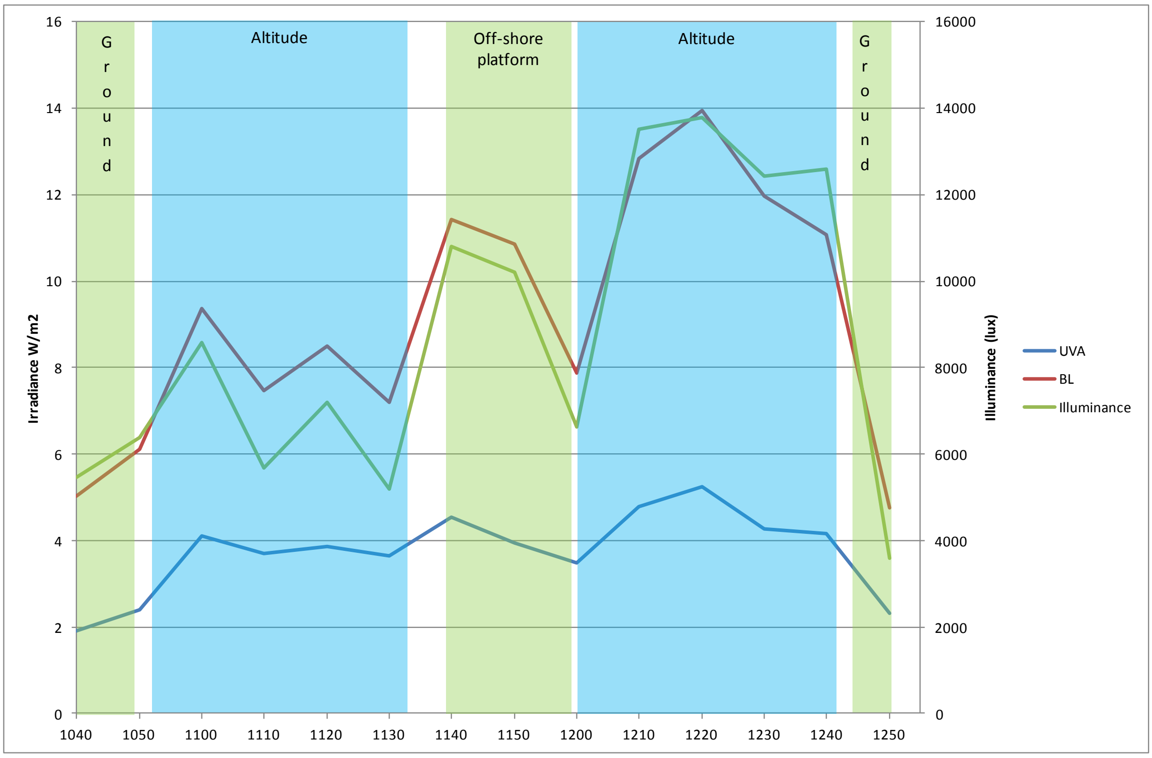

Figure 6-y Flight 7 summary of UVA, blue light and spectrometer illuminance.

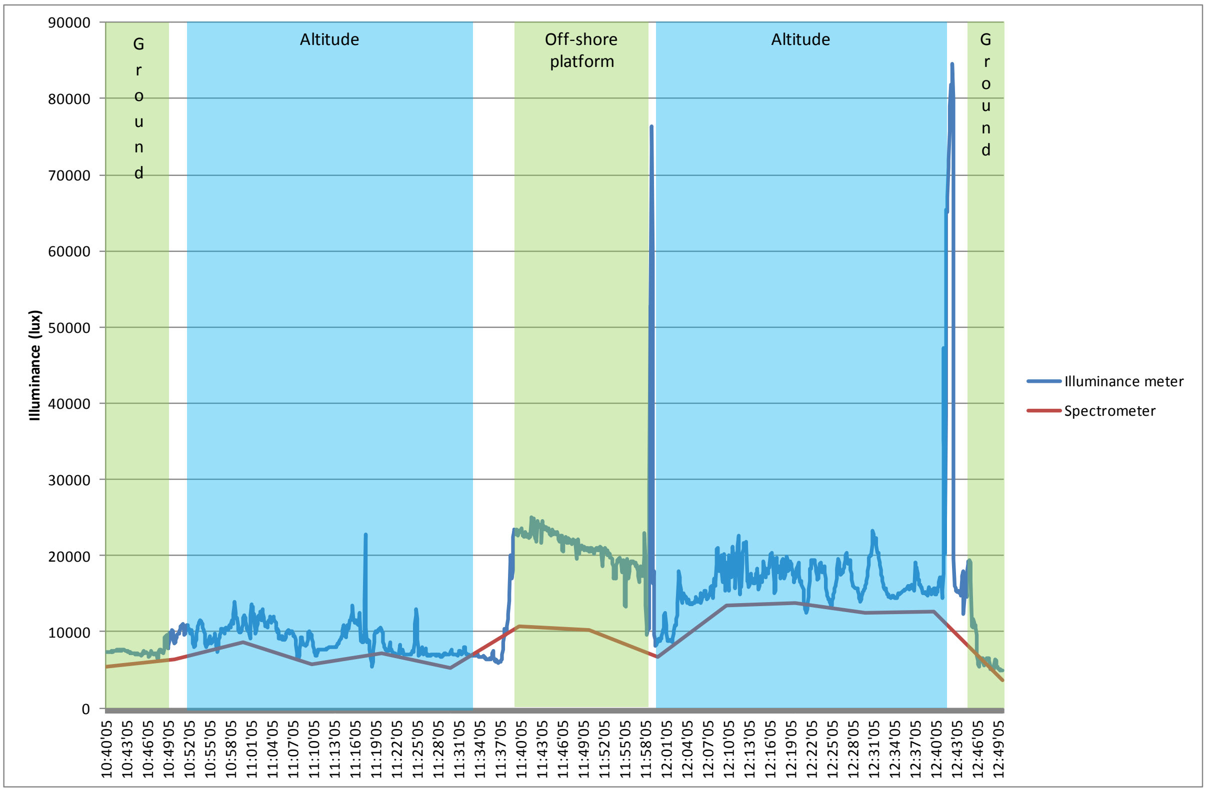

Figure 6-z Illuminance measured by spectrometer and illuminance UV recorder during flight 7.

6.2.13.2 Flight 8

A summary of UVA, blue light and illuminance levels during flight are shown in Figure 6-aa.

Broken cloud was observed on departure. The cloud base was observed marginally above the aircraft during the start of the outbound sector at 3,000ft. By 15:08, there was no observed cloud ahead. During the return sector, at around 2,000ft, the sun was observable both directly and diffusely reflected on the sea surface. By 16:33 cloud was noted above. The cloud base height reduced during approach to Aberdeen Airport. Light rain was observed briefly on landing.

A summary of illuminance measurements from both spectrometer and illuminance UV recorder are shown in Figure 6-bb.

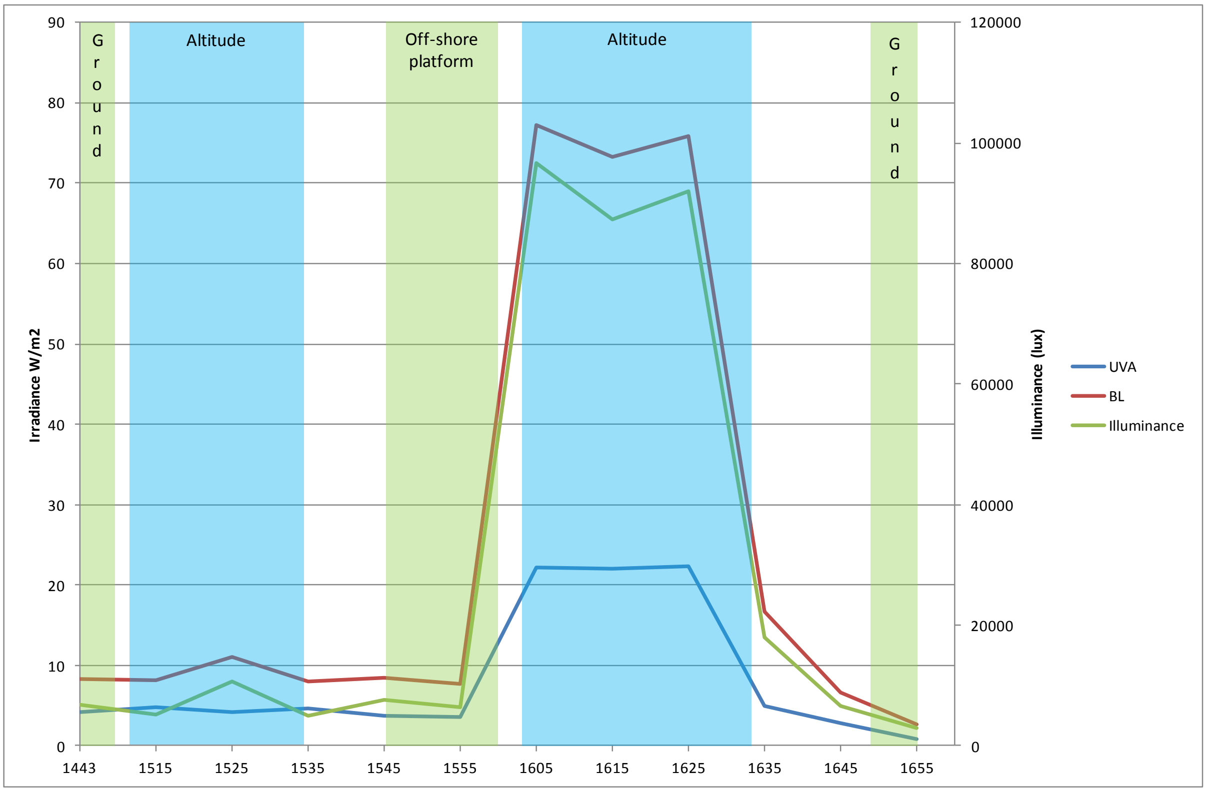

Figure 6-aa Flight 8 summary of UVA, blue light and spectrometer illuminance.

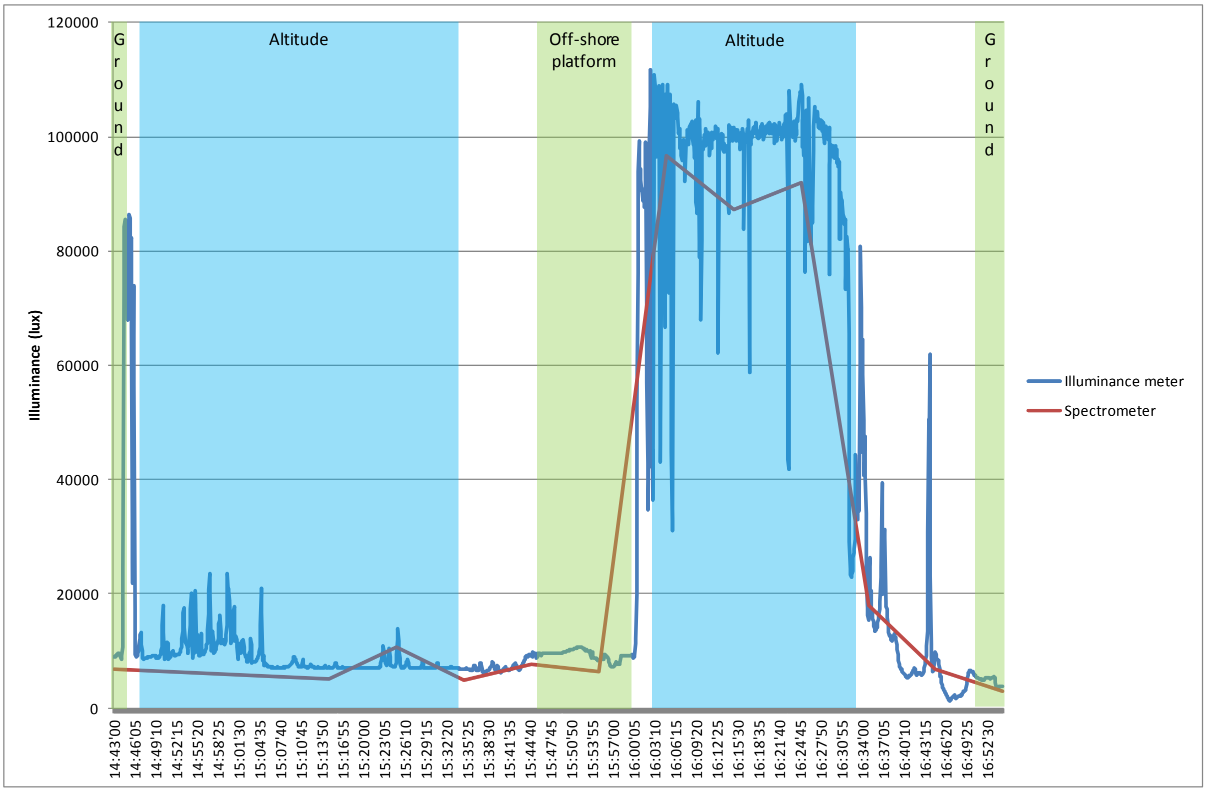

Figure 6-bb Illuminance measured by spectrometer and illuminance UV recorder during flight 8.

Illuminance spikes were measured during departure from and approach to Aberdeen airport. A number of spikes were also measured during the return sector. These were between 5 to 15 seconds duration.

UVA readings peaked at 22.3 W/m^2 at 16:25. Blue light peaked at 77.3 W/m^2 at 16:05, both of which were during the inbound sector at 2,000ft. The total UVA radiant exposure measured by the spectrometer was 6.47 x10^4 J/m^2. The total blue light radiant exposure measured during the same period was 1.92 x10^5 J/m^2. Comparing the illuminance data collected by both illuminance UV recorder and spectrometer resulted in a correction factor of 1.14. This would give revised values of 7.38 x10^4 J/m^2 for UVA and 2.19 x10^5 J/m^2 for blue light.

6.2.13.3 Flight 9

A summary of UVA, blue light and illuminance levels during flight are shown in Figure 6-cc.

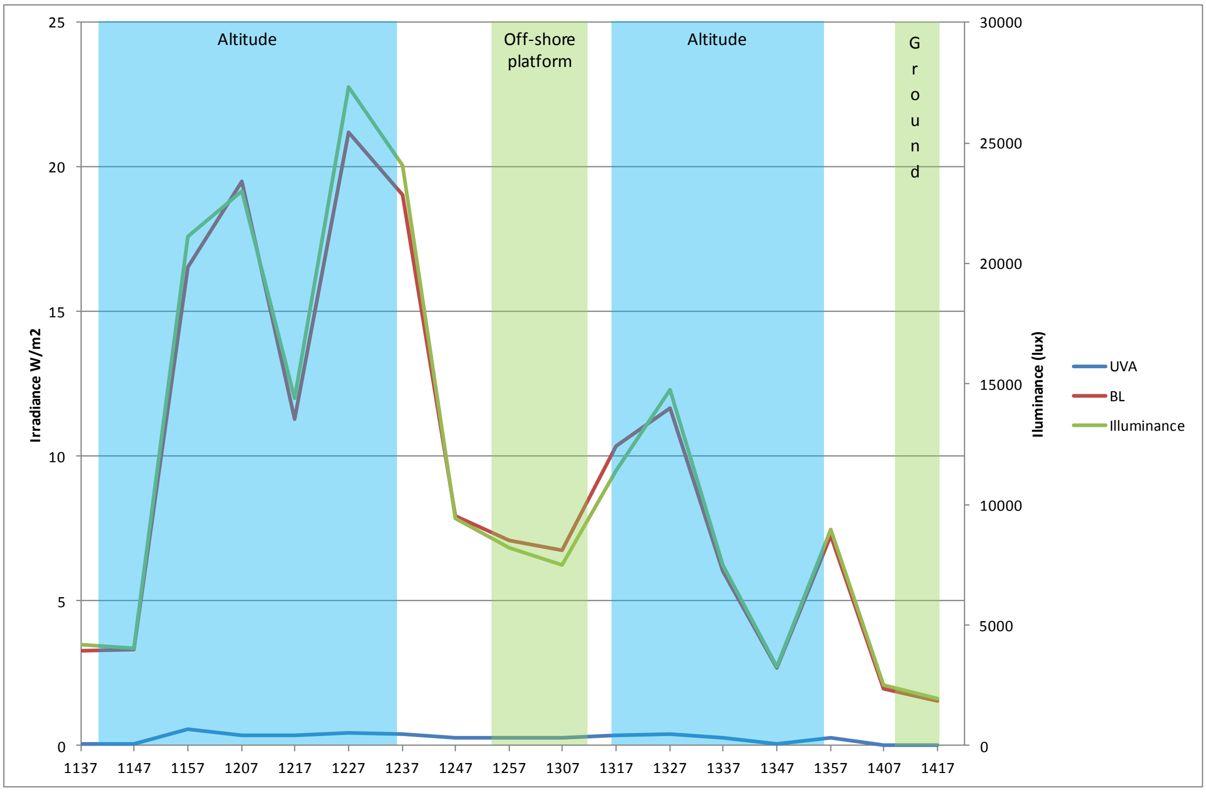

Figure 6-cc Flight 9 summary of UVA, blue light and spectrometer illuminance during flight.

Weather conditions were overcast on departure and outbound flight was in cloud until 11:56. From then until 12:25 the aircraft was intermittently in or just above cloud. The aircraft was in cloud during between 12:37 and 12:39 during descent and approach.

During the inbound flight, the aircraft entered cloud at 13:15 where it remained during the 2,000ft cruise sector. The sea surface was intermittently visible below during this time. A summary of illuminance measurements from both spectrometer and illuminance UV recorder are shown in Figure 6-dd.

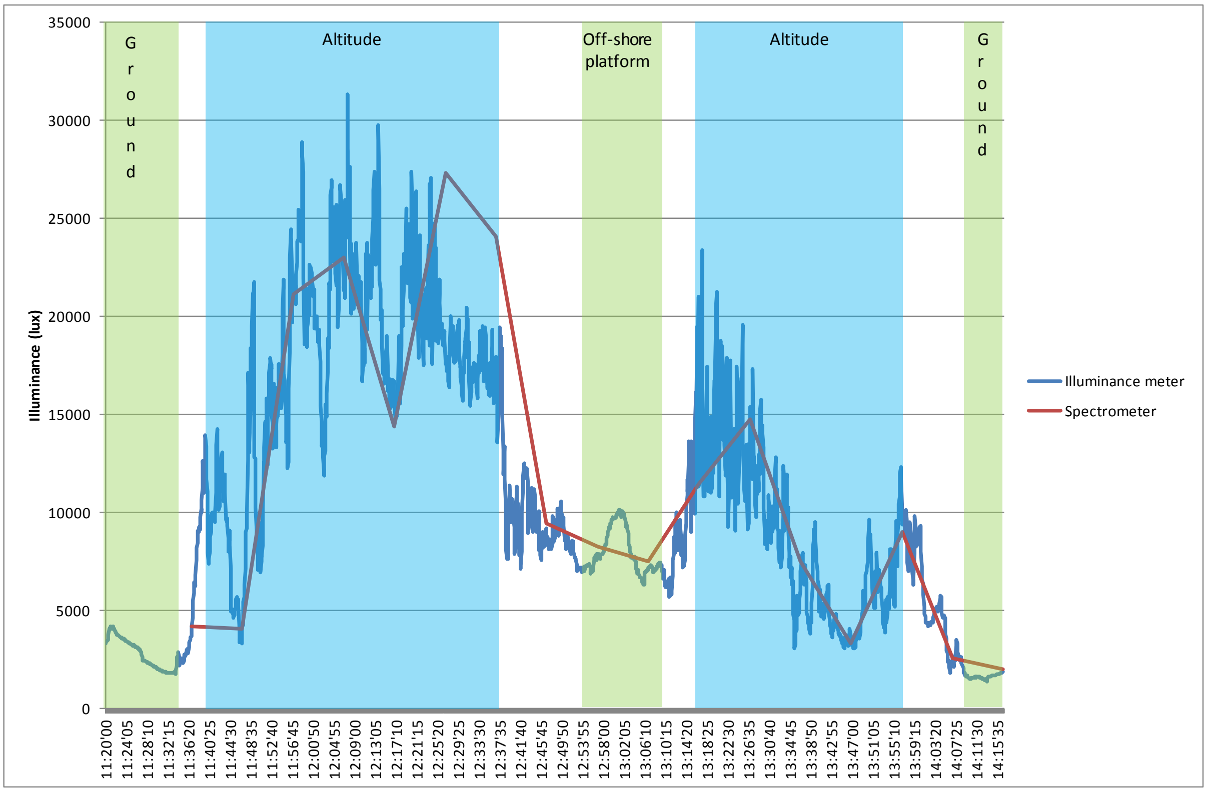

Figure 6-dd Illuminance measured by spectrometer and illuminance UV recorder during flight 9.

Short illuminance spikes were again seen during inbound cruise lasting typically 10 to 15 seconds. The greater overall fluctuations in illuminance are likely to be due to variable cloud present during flight.

UVA readings peaked at 0.6 W/m^2 at 11:57. Blue light peaked at 21.2 W/m^2 at 12:27 both of which were during the outbound cruise sector at 3,000ft. The total UVA radiant exposure measured by the spectrometer was 2.63 x10^3 J/m^2. The total blue light radiant exposure measured during the same period was 9.45 x10^4 J/m^2. Comparing the illuminance data collected by both illuminance UV recorder and spectrometer resulted in a correction factor of 0.94. This would give revised values of 2.47 x10^3 J/m^2 for UVA and 8.89 x10^4 J/m^2 for blue light.

6.2.13.4 Flight 10

A summary of UVA, blue light and illuminance levels during flight are shown in Figure 6-ee. No weather observations were available during this flight as the researcher was not able to be onboard. However, the weather remained overcast at Aberdeen airport for the duration of the flight. Illuminance measurements from both spectrometer and illuminance UV recorder are shown in Figure 6-ff.

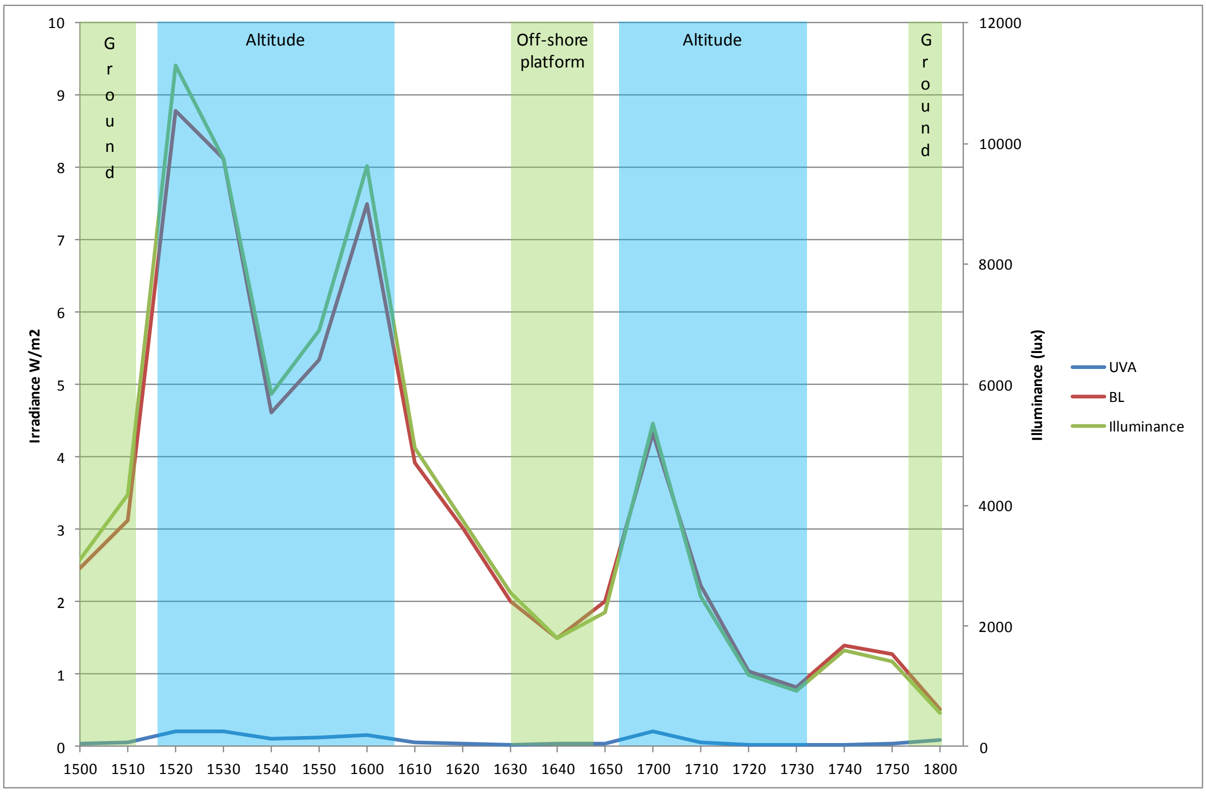

Figure 6-ee Flight 10 summary of UVA, blue light and spectrometer illuminance

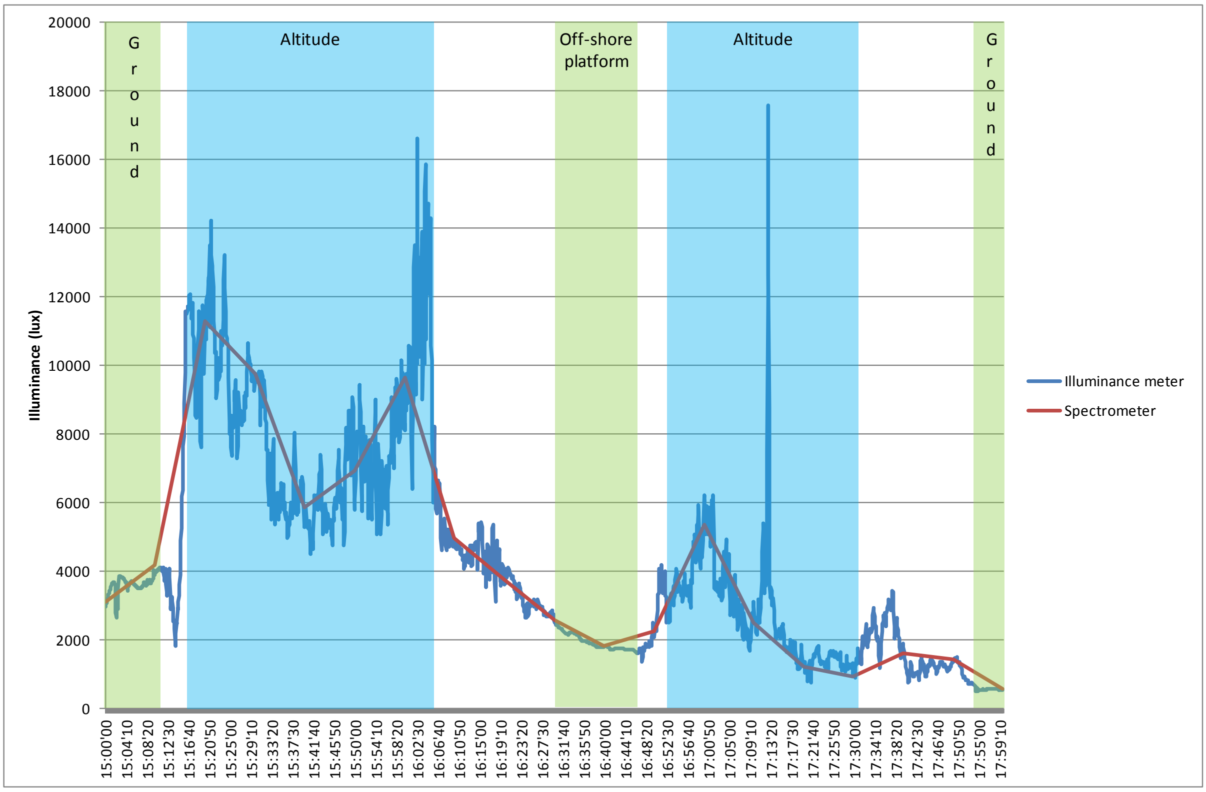

Figure 6-ff Illuminance measured by spectrometer and illuminance UV recorder during flight 10.

The large illuminance spike seen during the inbound sector was 5 seconds duration. The highest UVA readings of 0.2 W/m^2 were recorded between 15:20 to 15:30 and at 1700. Blue light peaked at 8.8 W/m^2 at 15:20 during the outbound cruise sector at 3,000ft. The total UVA radiant exposure measured by the spectrometer was 937 J/m^2. The total blue light radiant exposure measured during the same period was 3.84 x10^4 J/m^2. Comparing the illuminance data collected by both illuminance UV recorder and spectrometer resulted in a correction factor of 0.96. This would give revised values of 900 J/m^2 for UVA and 3.67 x10^4 J/m^2 for blue light.

6.2.14 Helicopter hazard ratios

The UVA hazard ratio is expressed as the un-weighted UVA divided by the illuminance for each reading (European Commission, 2006).

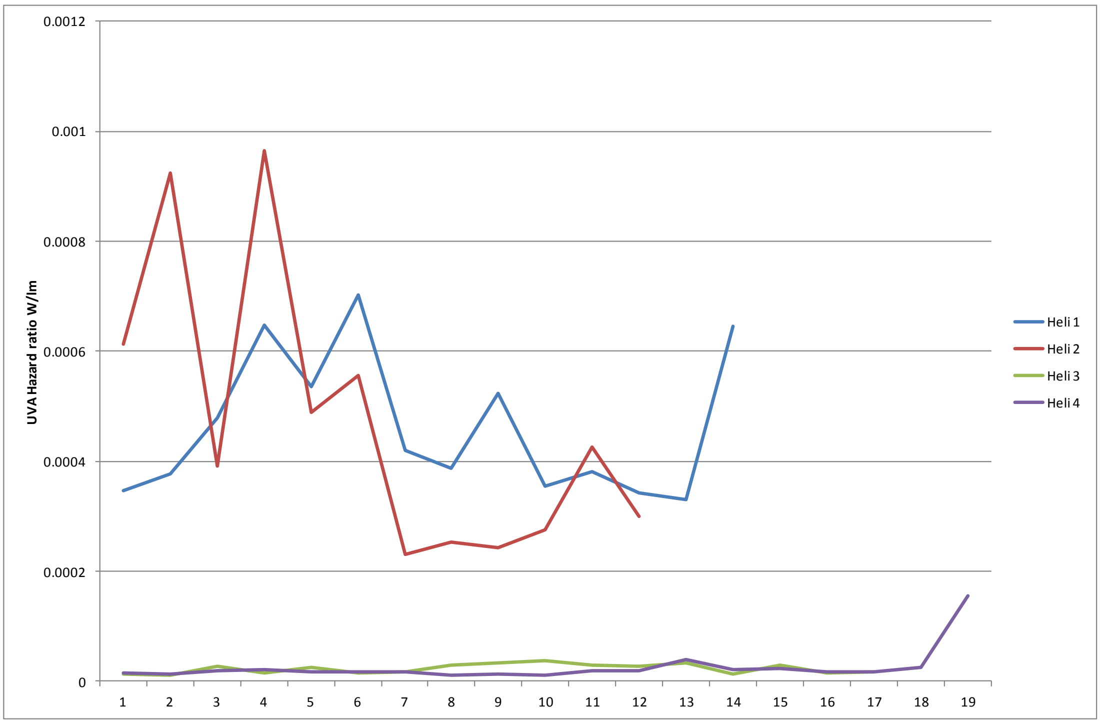

Figure 6-gg Calculated UVA hazard ratios throughout flight; x axis represents number of spectrometer readings taken.

Each flight is represented with consecutive readings plotted (Figure 6-gg). The horizontal axis is not time comparable between flights. It can be seen that UVA hazard ratios are significantly lower on flights 9 (Heli 3) and 10 (Heli 4) (S92a helicopter) compared to flights 7 (Heli 1) and 8 (Heli 2) (AS332 helicopter). A summary of BL hazard ratios for each flight are shown in Figure 6-hh.

It can be seen that UVA and BL hazard ratios on flight 8 (Heli 2) were lower on the inbound sector. This corresponded to a flight with a high signal in clear conditions flying in the direction of the sun.

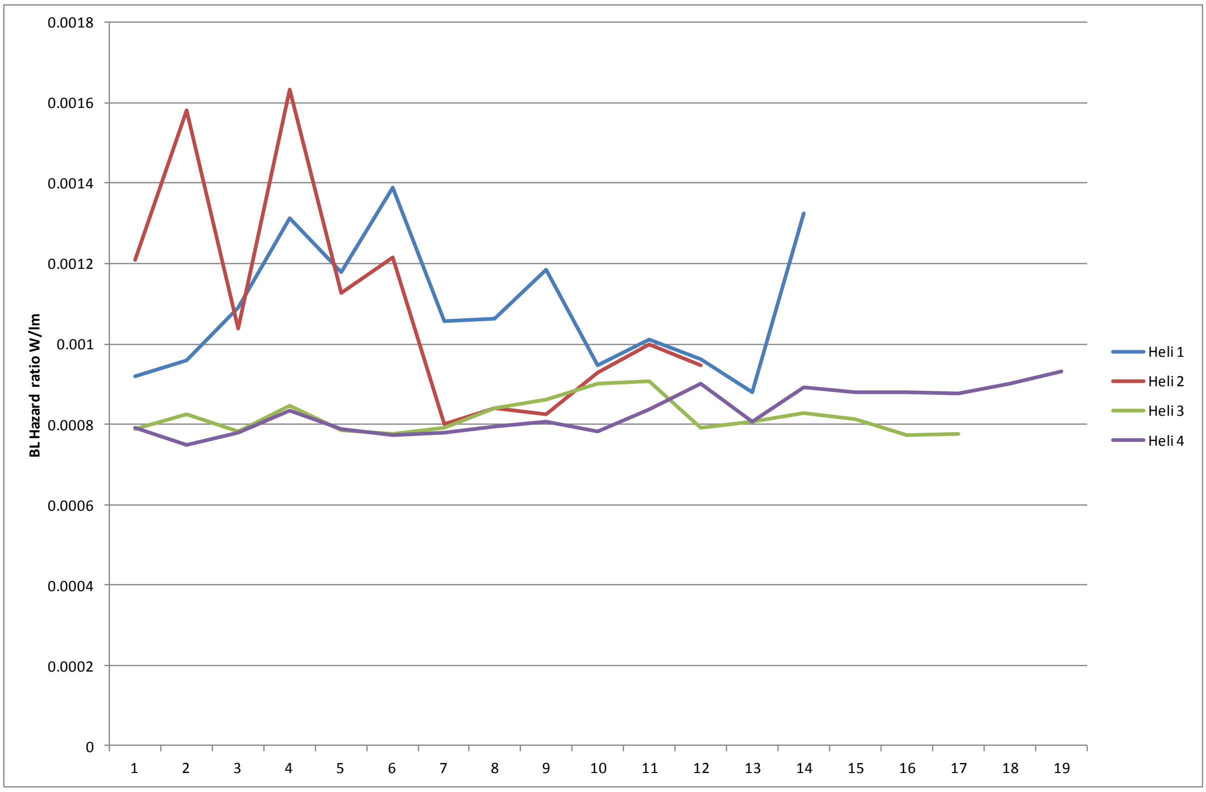

Figure 6-hh Calculated blue light hazard ratios throughout flight; x axis represents number of spectrometer readings taken.

6.2.15 Helicopter ocular exposure calculation

As the researcher was not able to be on board during flights 1 and 4, no manual illuminance data was available for these flights. However flights were conducted on the same day and on the same aircraft type on each occasion. An estimated ocular exposure is presented for flights 1 and 4 by using the average ratio of the two illuminance UV recorder readings throughout flights 2 and 3 respectively. The ratio used to calculate ocular exposure for flight 1 was 0.43 for eyes ahead and 0.25 for eyes towards instruments. The ratio used to calculate ocular exposure for flight 4 was 0.34 for eyes ahead and 0.22 for eyes towards instruments.

6.2.16 Helicopter ocular exposure to UV

A summary of UVA dose received for each flight is shown in Table 6-o. A proportion of the helicopter visual flying task is directed toward instruments whilst there is also a proportion of the visual task which would be directed ahead looking through the front aircraft windshield. As for aeroplane flights, ‘down’ and ‘ahead’ should be considered the minimum and maximum ocular exposure respectively. The values are shown are expressed in both dose (J/m^2) and as a proportion relative to the daily UVA exposure limit (10,000 J/ m^2) recommended under ICNIRP guidelines.

Flight	UVA dose				Flight duration (min)
	UVA ahead, J/m^2	Relative to ICNIRP guidelines	UVA down, J/m^2	Relative to ICNIRP guidelines	
7 Heli flight 1	14903	1.49	11804	1.18	121
8 Heli flight 2	28453	2.85	10320	1.03	134
9 Heli flight 3	955	0.10	589	0.06	155
10 Heli flight 4	309	0.03	200	0.02	163

Table 6-o Summary of UVA dose compared to ICNIRP limits for both eyes ahead and eyes down positions.

Overall, a mean 1.9 times increase in UVA was found at altitude compared to ground level on helicopter flights. The calculated ocular UVA dose per hour is shown in Table 6-p.

Flight	UVA per hour J/m^2 (ahead)	UVA per hour J/m^2 (down)
7 Heli flight 1	7390	4297
8 Heli flight 2	12740	6471
9 Heli flight 3	370	228
10 Heli flight 4	114	74

Table 6-p Summary of the calculated ocular UVA dose for both eyes ahead and eyes down positions.

6.2.17 Helicopter ocular exposure to blue light hazard

A summary of blue light radiance at the pilot's eye was calculated for each helicopter flight. There were no angle of pilot binocular visibility data available for either helicopter type flown. As discussed in section 6.1, where there is a uniform source, radiance measurements are relatively unaffected by open field or restricted (no less than 0.2 rad) scenarios. In practice, it is likely that the solid angle subtended by the extent of the front windshield is greater in both helicopter types compared with a fixed wing passenger aircraft flown (section 10.8). However, for the purposes of blue light weighted radiance calculations, the same solid angle value as used for flights 1 to 6 has been used. By using this approach, any errors incurred would give higher effective radiance values and the risk of exposure may be over-estimated. If this is the case, more detailed task analysis could be conducted however this would be of limited value where radiance or radiance dose were within ICNIRP guideline limits. The minimum, maximum, mean and standard deviations for each flight are shown for both eyes ahead (Table 6-q) and eyes down (Table 6-r) positions.

Maximum radiance to prevent type II damage = 100W/m^2.sr						Maximum radiance dose over 10,000 sec to prevent type II damage = 1x10^6	
Flight	**Mean Radiance W/m^2.sr**	**Standard deviation**	**Min Radiance W/m^2.sr**	**Max Radiance W/m^2.sr**	**Flight duration (min)**	**Radiance dose for flight (J/m^2.sr)**	**Relative to ICNIRP guidelines**
7 Heli flight 1	5.71	1.91	2.84	9.00	121	41467	0.04
8 Heli flight 2	14.00	17.07	1.27	77.11	134	112566	0.11
9 Heli flight 3	5.59	3.91	0.73	13.55	155	52033	0.05
10 Heli flight 4	1.61	1.22	0.24	4.15	163	15788	0.02

Table 6-q Summary of blue light hazard radiance for an eyes ahead position.

Maximum radiance to prevent type II damage = 100W/m^2.sr						Maximum radiance dose over 10,000 sec to prevent type II damage = 1x10^6	
Flight	**Mean Radiance W/m^2.sr**	**Standard deviation**	**Min Radiance W/m^2.sr**	**Max Radiance W/m^2.sr**	**Flight duration (min)**	**Radiance dose for flight (J/m^2.sr)**	**Relative to ICNIRP guidelines**
7 Heli flight 1	3.32	1.11	1.65	5.23	121	24109	0.02
8 Heli flight 2	6.69	5.70	0.56	24.67	134	53752	0.05
9 Heli flight 3	3.43	2.22	0.45	7.51	155	31884	0.03
10 Heli flight 4	1.04	0.79	0.16	2.69	163	10216	0.01

Table 6-r Summary of blue light hazard radiance for an eyes down position.

All blue light weighted radiance measured fell within recommended limit under ICNIRP to prevent type II retinal damage. The highest radiance value occurred during flight 8 during the inbound cruise flight when weather conditions were clear with no significant cloud cover. The aircraft was heading approximately west with an afternoon sun causing a large area of diffuse reflection from the sea surface visible to the pilot. Overall, a mean 2.5 times increase in blue light weighted signal was found at altitude compared to ground level for helicopter flights.

6.2.18 Helicopter ocular illuminance data

A summary of the average illuminance measured by both illuminance meter and spectrometer is shown in Table 6-s.

Flight	Av illum. Ahead (lux)	Av illum. down (lux)	Av illum at spectrometer (lux)
7 (Heli 1)	N/A	N/A	12626
8 (Heli 2)	10021	4866	26670
9 (Heli 3)	4551	2860	11395
10 (Heli 4)	N/A	N/A	4184

Table 6-s Summary of mean illuminance during flight as measured by spectrometer and manual illuminance UV meter.

As with the spectrometer data, illuminance readings taken at pilot eye level varied throughout flight. Minimum and maximum values recorded on each flight are shown in Table 6-t.

Flight	Min illum. Ahead (lux)	Max illum ahead (lux)	Min illum. down (lux)	Max illum down (lux)
7 (Heli 1)	N/A	N/A	N/A	N/A
8 (Heli 2)	1350 (desc)	26000 (alt)	600 (desc)	10500 (alt)
9 (Heli 3)	470 (grd)	9000 (alt)	290 (grd)	6000 (alt)
10 (Heli 4)	N/A	N/A	N/A	N/A

Table 6-t Summary of minimum and maximum manual illuminance readings. The phase of flight where the readings were taken is shown in brackets: grd = ground, alt = altitude cruise, desc = descent. Maximum and minimum readings for each flight occurred on the same timed measurement.

Overall, a mean 2.9 times increase in illuminance was found at altitude compared to ground level on helicopter flights.

6.2.19 Helicopter erythemal weighted irradiance

Erythemal weighted function was also included in the helicopter data analysis. Erythemal weighted irradiance, total erythemal UV dose (J/m^2) and SED were calculated (Table 6-u). Erythema doses were insignificant for all flights.

Flight	SED per flight	SED/hr
7 (heli 1)	0.189	0.09
8 (heli 2)	0.442	0.20
9 (heli 3)	0.284	0.11
10 (heli 4)	0.017	0.01

Table 6-u Summary of calculated SED per flight and per hour.

As for the aeroplane flights, these values are higher than the anticipated SED that the pilot would receive as the arms, hands and head of the pilot would be further back inside the cockpit and would not be expected to receive as high a signal as the spectrometer situated just behind the windshield. SED calculations at the pilot's face (considered the lower limit of erythema dose) were conducted in the same manner as for aeroplane flights (section 6.2.10) and are shown in Table 6-v. Furthermore, calculation for flight 7 involved using average ratio calculated in flight 8. Similarly, flight 10 used the average ratio from flight 9 as both involved the same aircraft. The average calculated SED over all helicopter flights was 0.04 SED/hr.

Flight	SED per flight	SED/hr
7 (heli 1)	0.081	0.04
8 (heli 2)	0.189	0.08
9 (heli 3)	0.097	0.04
10 (heli 4)	0.006	0.00

Table 6-v Summary of calculated SED at the pilot's face using ahead position illuminance UV meter data.

6.2.20 Observed eye protection practices employed during flight

Data were additionally collected of eye protection practices observed of both pilots during flight. There were no non-standard practices of blocking sunlight observed during aeroplane flights except briefly on flight 6.

There were no observed eye protection practices used at any point during flight 1. During flight 2, the captain (left seat) wore sunglasses once established at cruise altitude for the remainder of the outbound flight. The first officer (right seat) deployed the aircraft front visor above FL200 (section 1.5.2) for the majority of the sector. On the return sector, both captain and first officer wore sunglasses from when the aircraft was pushed back from the stand at Faro. During cruise altitude, the first officer was also observed to deploy the side blind on three occasions from just before reaching cruise altitude until 5 minutes before landing. The total time the side blind was used was approximately 1 hour 15 minutes.

On flight 3, the first officer wore sunglasses for the duration of the outbound flight and for the final 20 minutes of the inbound flight. The captain was not observed to use sunglasses. Both captain and first officer used front visors from immediately after takeoff. The captain also used his side window blind once established at FL330. These were used until 3 minutes before landing. On the return sector, the first officer used his side blind for approximately 1 hour 10 minutes during cruise at FL380.

During flight 4, the first officer used his front visor from immediately after takeoff. During the climb, both pilots used their side window blinds. Once at FL300, the captain also used his front visor and a small visor between the pilots. During cruise, the captain stowed his visor for approximately 35 minutes and the first officer stowed his visor away for approximately 40 minutes. The side blinds and centre visor were stowed just before commencing descent and both visors were stowed during the final 6 minutes of flight. Neither pilot was observed to use sunglasses during flight.

On flight 5, the first officer wore sunglasses for the duration of the outbound flight and from just after takeoff on the inbound flight. The captain was not observed to wear sunglasses. The captain deployed his front visor from near the top of the climb and positioned it between front and side windshields. The captain also used his side window blind during descent toward Alicante. Both visor and blind were stowed four minutes before landing. During the return sector, the first officer used his front visor for a brief period during climb. The captain used his side blind from just after takeoff and his front visor from near the top of the climb. Both were stowed within nine minutes before landing.

During flight 6, the captain wore sunglasses for the duration of both sectors. The first officer used his sunglasses from take off until early descent towards Rhodes and from when the aircraft achieved cruise altitude on the inbound sector until landing at London Gatwick. On the outbound flight, the first officer deployed his visor twice during cruise altitude for a total of approximately 1 hour 50 minutes. During the inbound sector, the captain deployed his front visor just after takeoff and his side window blind once established in the cruise. These remained in place until commencing the descent. The captain was also observed to use his hand to shield sunlight from his eyes briefly during takeoff from Rhodes and again during final approach at London Gatwick when the first officer was also using his hand to shield his eyes from a low sun in line with the runway.

During helicopter flights, visors were not fitted on the aircraft flown. During the inbound cruise during flight 8(b), the captain was observed to use a laminated check list under her headset as a makeshift peaked cap to shield her eyes. On flight 9(a), the captain used his sunglasses for approximately the final 30 minutes of the outbound flight.

6.2.21 Limitations of data

6.2.21.1 Pixel saturation

As discussed in section 5.7, a small number of readings suffered signal saturation and potential pixel leakage. As this can affect the accuracy of the data, these measurements were not used for analysis.

6.2.21.2 Shutter

The Ocean Optics INLINE-TTL-S optical shutter is gravity operated for one state, thus depending on its orientation will be open or closed. As ASAS software program monitors irradiance levels between measurements, the shutter was always orientated to remain open and battery power was then required only during dark measurements. The battery failed during the flight 4 (Tobago). This meant that spectral data were still collected but without a dark measurement.   Therefore, for every region at every 10 minute interval, two equivalent spectral readings were obtained. Although a metallic click can be heard when the shutter operates, it was often not possible to hear this in the cockpit environment as a headset was worn and the equipment was often not sited next to the researcher. In the helicopter environment, the shutter noise could not be detected. This shutter failure came about through an incorrect battery charging procedure. Following flight 4, charging instructions from the unit on loan from HPE were made available. It was apparent that the battery could only be charged when switched on. Subsequent measurements revealed an intermittent failure of the shutter to operate. This intermittent error was found difficult to reliably replicate, however it was thought to be due to a fault within the cable from the battery to the TTL control unit. Spare cables and batteries were carried during later flights.

A series of dark measurements were taken with the HR4000 in the HPE laboratories and were used as a reference standard. These were taken at various board temperatures (5^{o}C, 10^{o}C, 15^{o}C, 22^{o}C, 30^{o}C and 40^{o}C) and integration times (5ms, 10ms, 20ms, 50ms, 100ms, 300ms, 500ms, 700ms, 1s, 2s, 5s and 10s). The closest dark reading was used and inserted into those data files without a dark measurement.

The spectral signal was generally strong and dark data from shorter integration time reference standards was usually required. Additionally, having a strong signal meant that effect of inaccuracies in background data would be reduced. Data points requiring dark data showed good correlation to illuminance UV meter readings.

6.2.21.3 Illuminance UV recorder

Both illuminance UV recorders were always fitted with new AA batteries before flight. For flights 1-3, the illuminance UV recorder coupled to the spectrometer was pre-programmed the day before deployment in order to reduce workload in setting up the equipment on the day of data collection. On flight 3, it was found that the new battery inserted on the previous day was registering as flat and had to be replaced. Although spare AA batteries were carried, the pre-programmed settings had been lost. It was not possible to re-programme the illuminance UV recorder for automated data collection as the appropriate USB cable was not available. Both illuminance UV recorders were therefore read manually during this flight. For subsequent flights, a spare cable was carried and the illuminance UV recorder was generally programmed just before departure.

6.3 Discussion

6.3.1 Ocular exposure

The calculated ocular exposure of UVA on different flights varies widely. Flights 2 and 3 were conducted at near identical times of year and time of day. The destination was the same and the flight times were very similar. Weather conditions for both flights were similar and relatively cloud free. The equipment and measurement protocol was identical. The aircraft type (Airbus A320) was the same on each flight, however the two individual aircraft were different. The aircraft used for flight 2 was built in 2001 and had a total flight time of 37,526 hours logged at 31/12/2012. The aircraft used for flight 3 was built in 1994 and had a total flight time of 69,461 hours logged at 31/12/2012. The pilot flying the newer aircraft received over 11x the UVA dose to that of the pilot flying the older aircraft. The large difference in exposure was due to differences in the transmission properties of the two aircrafts' windshields.

An example of a spectral reading taken at cruise altitude on each outbound flight is shown in Figure 6-ii.

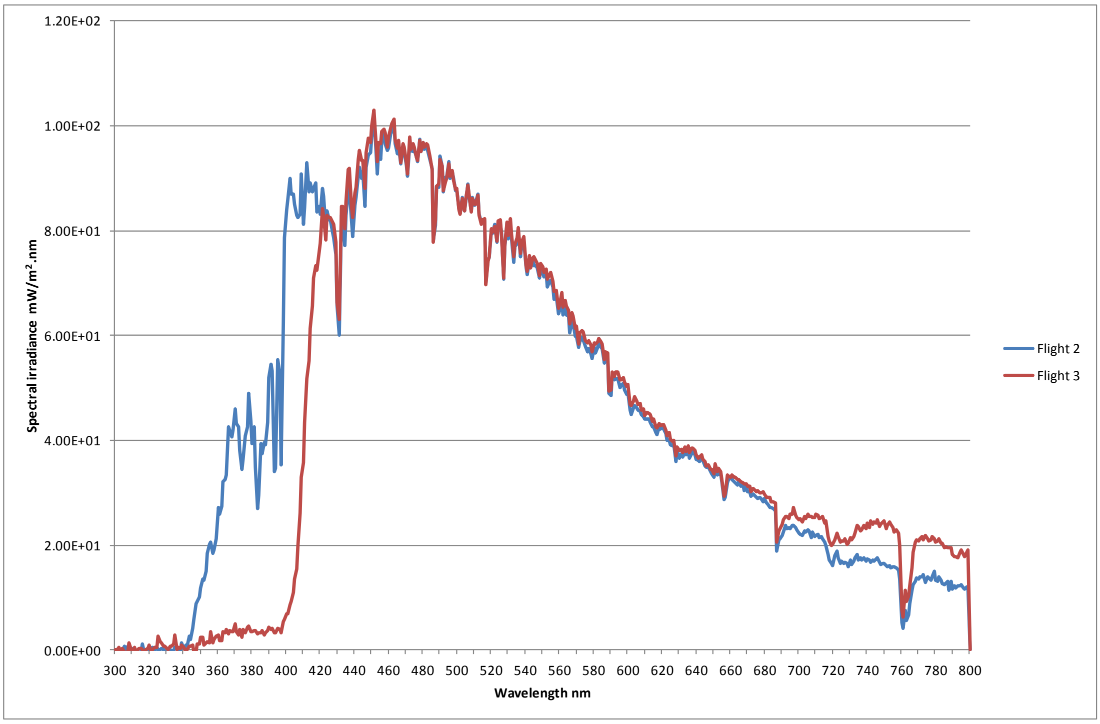

Figure 6-ii Sample spectral data measured during cruise on flights 2 and 3 show the difference in windshield attenuation properties.

The two spectra are similar from 420 - 700nm, however a large difference in the irradiance between 350 – 420nm can be seen. UVA dose is therefore highly dependent on the type of windshield installed. It is clear from the data that flights 3 (Barcelona) and 4 (Tobago) were undertaken in aircraft with good UVA attenuating properties. This finding prompted a series of windshield transmittance measurements to be conducted from various aircraft on the ground. This is described in chapter 8.

Data show that ICNIRP guidelines for UVA ocular exposure can be exceeded for even a relatively short two sector flight such as London Gatwick to Barcelona. Flight 6 demonstrated the highest calculated UVA dose being around 4.5 to 6.5 (depending on eye position) times greater than ICNIRP guidelines. This flight was particularly chosen as it was a morning departure from London Gatwick with an easterly component to the heading and returned from Rhodes during the afternoon with a westerly component to the heading. This was a longer two sector flight and was in a similar direction to the solar azimuth. It was therefore anticipated that a potentially high ocular dose would result if measurements took place in an aircraft with poor UV attenuating windshield properties. The presence of cloud below the aircraft during the inbound sector is likely to have increased exposure further due to reflection of radiation from cloud tops. It should however be noted that on this flight, both captain and first officer wore sunglasses for the majority of the flight. Therefore, in this particular instance actual ocular UVA exposure received by the pilots may be significantly less than ICNIRP guideline limits depending upon the transmission properties of the sunglasses used (see chapter 9).

A large difference in calculated UVA dose can also be seen within the helicopter flights with the aircraft flown for flights 9 and 10 having better UVA attenuating properties than the aircraft flown for flights 7 and 8. Indeed the reference manual for the Sikorsky 92a describes the aircraft to have a glass/acrylic plastic laminate windshield. It is likely that the addition of this plastic layer in the windshield construction offers better UVA protection to the pilots. Clear acrylic material can, with additives, be manufactured to block up to 98% of UV (Ridout Plastics, no date). It is likely that this is responsible for the low UVA detected in this aircraft.

Although flights were taken on consecutive days at similar times of day, weather conditions for flights 7 and 8 were much sunnier and cloud free compared to the second day, which was more overcast and involved more flight time in or below cloud. The data from the two days of flights are likely to indicate the range of ocular exposure for the off shore helicopter pilot with flights 7 and 8 carried out in bright conditions in an aircraft with poor UVA attenuating windshields and flights 9 and 10 being carried out in dull, overcast conditions mainly in cloud with little direct sunlight seen in an aircraft with good UVA attenuating properties.

As the use of eye protection strategies in flight is mainly driven by the need to block sunlight and provide ocular comfort, as was found in section 4.9, a greater use of strategies would be expected in situations where a high blue light hazard dose were present. The effectiveness of typical pilot sunglasses to block the blue light hazard is discussed in section 10.11.

UVA hazard ratios were low throughout flight on aircraft with good UVA attenuating properties. It can be seen that blue light hazard ratios and UVA hazard ratios on aircraft with poor UVA attenuating properties appear inversely related to overall illuminance. Therefore, the sectors with high illuminance measured had relatively lower hazard ratios, and those sectors with lower illuminance had higher hazard ratios. Flight 6 was the only two sector flight where the presence of cloud was significantly greater on one sector. On this flight, the inbound sector was flown above significantly more cloud but with lower overall irradiance levels and significantly higher hazard ratios were found. This finding confirms the UV enhancing effect of cloud as discussed in section 1.4.6. Again, as eye protection strategies are strongly driven by overall illuminance, sunglasses are less likely to be worn when hazard ratios are higher.

6.3.2 Solar azimuth and elevation

The position of the sun relative to the input optics of the spectrometer or the pilot's eyes is a large factor influencing potential irradiance received. Most two sector flights show a difference in irradiance between outbound and inbound cruise. Clearly, if the headings of the two sectors are different by 180^{o}, so too will be the solar position relative to the pilots. Those flights with a marked difference between outbound and inbound sectors will have had direct radiation captured by the spectrometer for most or all of one of the cruise sectors.

6.3.3 Effect of reflection from cloud top

From the data collected, it is not possible to quantify the degree of this effect. However, the presence of a surface reflecting a higher percentage of radiation at a closer distance than the ground is likely to cause an increase in radiation reaching the aircraft cockpit windshield. It is known that short wavelength radiation will be subject to greater scattering which is likely to cause a higher relative irradiance of short wavelengths compared to the overall spectrum and that the presence of cloud can enhance UV dose (section 1.4.6).

Flights 5 and 6 showed the largest difference in hazard ratios between outbound and inbound flights. Both flights had significantly higher overall irradiance levels on the outbound sector compared to the inbound and both had a heading which resulted in the relative solar azimuth angle such that the solar disc would have been directly visible to the pilot (section 6.2.4). Data in these outbound sectors would therefore be comprised of a high proportion of direct radiation. The inbound sectors of both flights were more likely to receive diffuse radiation, enhanced in the short wavelengths by reflection from cloud tops.

6.3.4 Illuminance spikes

A number of short duration increases (and decreases) in illuminance are seen on most flights. They constitute a small proportion of the total flight time and are generally not present during the cruise phase of flight.

Large spikes in illuminance are recorded on multiple occasions during periods of flight where the aircraft is undergoing large changes of heading. This is particularly seen during taxy and approach to land phases of flight. Large illuminance spikes were also seen during takeoff and climb, where the aircraft adopts a significantly greater nose up attitude which has the effect of reducing the relative solar elevation angle to the pilot's eye. This could also mean that the sun at a high elevation angle is obscured by the aircraft structure while the aircraft is on the runway and is then directly visible during climb. In other words, the illuminance spikes may represent the change from indirect light to direct sunlight falling on the probe.

Helicopters are more able to conduct fast changes of heading particularly after transiting from the hover into forward flight. With no airspace restrictions present, they are able to quickly take up the desired heading. Additionally, as the cruise altitude is lower there is a short time between ground and reaching cruise altitude. Helicopters adopt a more nose down attitude during climb and any illuminance spikes seen during climb on helicopter flights are likely to be due to changes of heading. Helicopters are also likely to cruise with a more nose down attitude than fixed wing aircraft (this is one component of the flight controls which determines the speed of the aircraft) which would result in a marginally higher solar elevation angle relative to the pilot.

More illuminance spikes and variation in signal are seen from the illuminance UV recorder during helicopter cruise compared to aeroplane flights. These were more apparent on flights 8 and 9. It is possible that as the helicopter operates near cloud, these spikes are partly due to flying in and out of cloud. It is also possible that the main rotor blades tips of the helicopter may have been in the line of sight between the sun and illuminance UV recorder and have temporarily affected readings. The weather conditions and solar position relative to the aircraft on the inbound flight 8 would meet these criteria. Finally, it is possible that the Illuminance UV meter was in some way affected by aircraft vibration however the illuminance spikes were not consistent throughout all helicopter flights.

6.3.5 Aircraft windshields

Although visual inspection revealed no observed differences of the windshields installed on the aircraft flown, there were large differences in UVA dose measured on different aircraft. Flights with a low UVA irradiance showed the windshield to have a sharp transmittance cut off around 400nm. Therefore, onboard these flights, only a minimal UVA signal was detectable. On board an aircraft with a good UV blocking windshield, the UVA dose is unlikely to exceed ICNIRP guidelines regardless of the flight time, position of sun or external conditions. Windshields from flights with a higher UVA dose showed a gradual increase in transmittance of radiation from around 360-365nm. Flights on board a poorer UVA blocking windshield have been shown to easily result in a UVA exposure in excess of ICNIRP guidelines. This may occur where flight conditions may not feel excessively bright to the pilot. As the pilot currently has no means to assess the UV blocking properties of a particular windshield, they may inadvertently be subject to a significantly higher UVA dose without using appropriate eye protection.

6.3.6 Flight 4 (Tobago) illuminance and pilot exposure

The spectrometer and paired illuminance UV meter measured the highest levels of overall illuminance of all flights undertaken with measurements peaking at over 120,000 lux. Additionally, this flight was also the longest duration at nearly 10 hours, all of which were during daylight. However, the results showed a lower calculated ocular exposure than other flights. As previously discussed, the UVA dose was found to be within ICNIRP guideline limits due to the good attenuation properties of the aircraft windshield. Additionally, the average illuminance at the pilot's eye level during flight was found to be lowest of all aeroplane flights. This is thought to be due to the cockpit design of the Airbus A330. The aircraft has wide pull down visors for each pilot's front windshield. These, when fully extended, cover a greater proportion of the windshield area than other aircraft types encountered. Additionally, a central visor is available (Figure 6-jj). These, together with the roller blinds for side windows were used during flight and allowed the pilots greater control of cockpit illuminance. Indeed the pilots on this flight did not use sunglasses despite the bright external conditions.

Figure 6-jj A330 cockpit offering a larger area of front windshield coverage.

Due to this enhanced control of cockpit illuminance, the calculated ocular dose of blue light hazard was also the lowest of all aeroplane flights. Flight 4 demonstrates the importance of transmission properties of aircraft windshields and design of visors in protecting the non-sunglass wearing pilot.

6.4 Summary

This chapter has demonstrated that higher irradiance levels of UVA and blue light are present at altitude compared to ground level. The mean increase in UVA during airline flights was 2.4 times higher and the mean increase in blue light hazard was 4.1 times higher at altitude. During helicopter flights, the increases measured were 1.9 times for UVA and 2.5 times for the blue light hazard. Erythemal weighted irradiance was low due mainly to the UVB blocking properties of all windshields.

Calculated blue light hazard radiance always fell within ICNIRP guideline limits however, ocular irradiance to UVA exceeded ICNIRP exposure limit guidelines during four airline flights. The key determinant of high UVA exposure was not the external conditions, but rather the differences in windshield attenuation properties. In order to investigate this important finding further, ground aircraft windshield transmittance readings have been captured on a series of airline aircraft of differing types and these results are described in chapter 8. First, in chapter 7, data are provided for comparison of pilot UVA and blue light exposure to sample office workers.

7. Chapter 7 Office Measurements

CHAPTER OVERVIEW

This chapter describes spectral measurements using the HR4000 in order to assess the typical ocular exposure at a series of office workstations. Data are collected over an eight hour working shift and are repeated at different times of the year. The results of this chapter offer a comparison to the ocular exposure measured during flight for both airline and helicopter pilots as described in chapter 6.

7.1 Introduction

In addition to capturing spectral data on high altitude jet airline operations and low altitude helicopter operations, it was additionally decided to obtain some comparative data from a more commonplace working environment. Occupational exposure data were captured from a series of office workstations in the CAA Safety and Airspace Regulation Group building at Gatwick Airport South, West Sussex.

7.2 Method

Three workstation locations were selected. The first (workstation 1) was a ground floor location in a room with large windows across both south and west facing walls. The workstation was situated near the south facing window. Workstation 2 was located on the ground floor, facing south in an open plan office area nearer the centre of the building and away from any external windows. Limited natural daylight was visible through the glass ceiling above the third floor of the nearby atrium. Both workstations were lit by overhead ceiling fluorescent tube lighting. Workstation 3 was the researcher’s consulting room which contained no windows and had no access to daylight. Lighting was provided by overhead ceiling fluorescent tube and tungsten spot lighting.

Following agreement from the CAA employees whose workstations were selected, data collection was carried out during normal office hours on dates when the workstations were available. As it was then possible to set the spectrometer input optics at the likely office worker eye level and facing toward the computer and desk area of their workstation, the illuminance UV recorders were not used. The detector and fibre optic cable were optimally positioned by securing to a camera tripod using electrical tape. ASAS was set to collect data every 10 minutes over an eight hour continuous period using the same settings as for all flight data collected.

Measurements from each workstation were taken during both February 2013 and July 2013. For workstation 1, data collection took place on days where the room was not being used. Data collection for workstation 2 took place on days when desk was vacated. The spectrometer was set up for workstation 3 so that the researcher was able to continue working in this office during data collection.

Data collection from workstation 1 was carried out during days that were clear and mainly sunny. It is possible that the solar disc was obscured by cloud for short periods during data collection. The room containing workstation 1 had horizontal blinds fitted. Two days of data collection at this location were carried out in February 2013. The first with the blind slats closed and the second day with the blind slats open but with the blinds not raised. One day of data collection were carried out in July 2013 with the room blind slats open but not raised.

Spectrometer data were analysed in the same way as for in flight measurements (section 6.1). However, as there were no illuminance UV recorder data, ocular exposure calculations were made directly from the spectrometer data.

7.3 Results

Each complete spectrum was a result of six measurements: a spectral and dark measurement for each of the three regions. There were no saturated spectra. Dark spectra measured under standardised conditions described in section 6.2.21.2 were applied in cases of shutter failure. No spectra required stitching (Table 7-a).

The dose results for UVA are summarised in Table 7-b. Also shown is the average illuminance measured by the spectrometer at the simulated eye position of the office worker although it should be noted that these illuminance figures do not equate to typical recommended office guidelines which relate to illuminance of the task and not irradiance at the eye.

Office workstation no.	No of complete spectra	No of saturated spectra	No of spectra with non-operational shutter	No of spectra requiring stitching
1 (winter BC)	49	0	0	0
1 (winter BO)	49	0	0	0
1 (summer BO)	49	0	0	0
2 (winter)	48	0	0	0
2 (summer)	49	0	8	0
3 (winter)	49	0	0	0
3 (summer)	49	0	0	0

Table 7-a Summary of data collected by spectrometer during office measurements. BC = window blinds closed; BO = window blinds open.

Workstation	UVA dose, J/m2	Relative to ICNIRP guidelines	Average illuminance (lux)	Duration (min)
1 (winter BC)	2281	0.23	342	490
1 (winter BO)	2291	0.23	361	490
1 (summer BO)	2200	0.22	125	490
2 (winter)	1930	0.19	146	480
2 (summer)	2158	0.22	126	490
3 (winter)	2818	0.28	125	490
3 (summer)	2835	0.28	120	490

Table 7-b Summary of UVA dose compared to ICNIRP limits together with average illuminance and data recording duration of each workstation.

A summary of blue light radiance measured at office workstation is shown in Table 7-c. Measurements were considered open field and not restricted. As with helicopter data and to provide a conservative calculation of effective radiance and radiance dose in relation to the guidelines, the same solid angle was used as for flight data.

Maximum radiance to prevent type II damage = $100 W/m^2.sr$						Maximum radiance dose over 10,000 sec to prevent type II damage = $1x10^6$	
Workstation	Mean Radiance $W/m^2.sr$	Standard deviation	Min Radiance $W/m^2.sr$	Max Radiance $W/m^2.sr$	Duration (min)	Max radiance dose over 10,000 sec ($J/m^2.sr$)	Relative to ICNIRP guidelines
1 (winter BC)	0.46	0.74	0.08	5.04	490	8314	0.008
1 (winter BO)	0.47	0.71	0.10	3.79	490	7139	0.007
1 (summer BO)	0.43	0.19	0.21	0.92	490	4588	0.005
2 (winter)	0.11	0.01	0.09	0.13	480	1156	0.001
2 (summer)	0.11	0.03	0.05	0.16	490	821	0.001
3 (winter)	0.10	0.01	0.06	0.12	490	960	0.001
3 (summer)	0.10	0.01	0.08	0.11	490	912	0.001

Table 7-c Summary of mean, minimum and maximum blue light hazard weighted radiance measured together with comparison to calculated ICNIRP recommended exposure limit.

All blue light weighted effective radiance measurements were minimal when compared to ICNIRP guideline limits for type II retinal photochemical damage. Office data was unsurprisingly lower than flight data. Also expected was that workstation 1 would show a higher blue light weighted radiance due to the influence of natural daylight. This also explains the higher standard deviation values due to the gradual shift in relative solar position throughout the measurement period and the presence of any cloud cover. It would seem that there was little or no effect of natural daylight on measurements captured from workstation 2 as data is similar to that taken from workstation 3 with no natural daylight present.

The calculated doses from all workstations at both times of year fell within ICNIRP guidelines for UVA and blue light hazard doses. The graph shown in Figure 7-a shows a summary of the variation in measurements throughout each data collection.

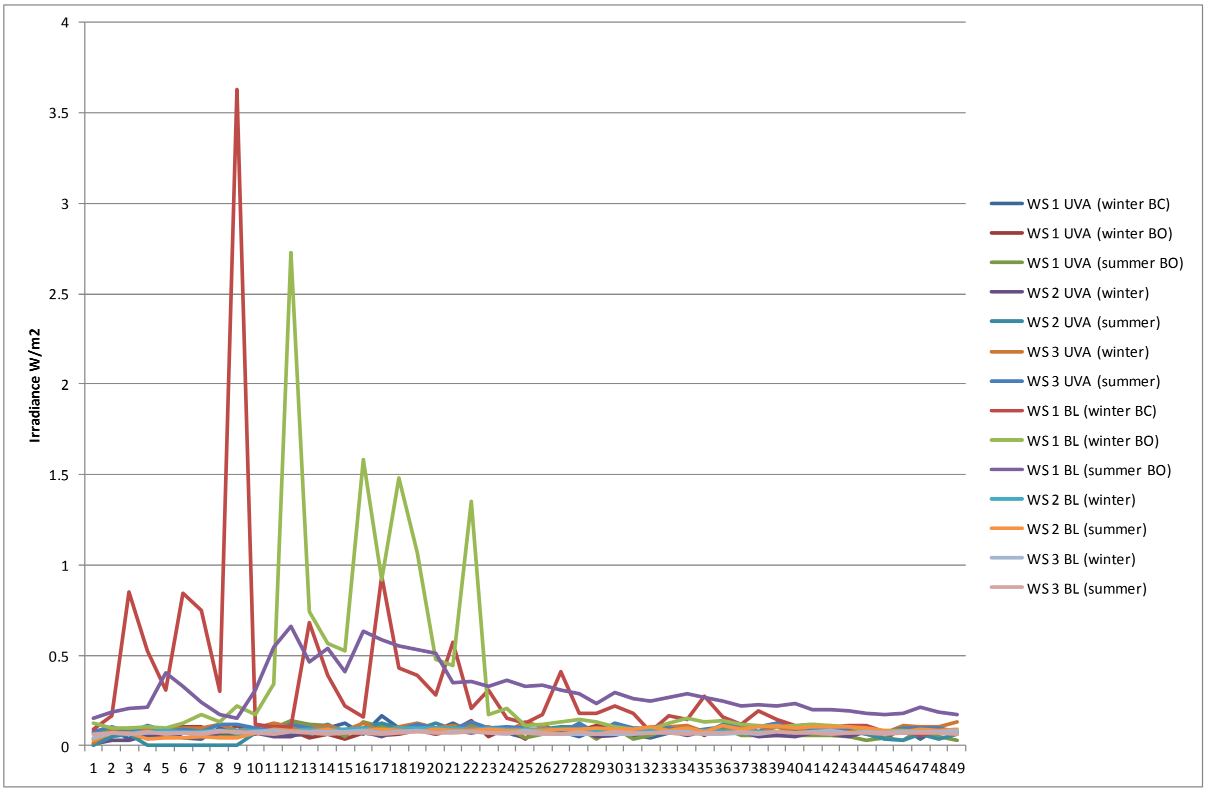

Figure 7-a UV and Blue light hazard ratios throughout data collection period; x axis represents the number of spectrometer reading taken. WS = workstation, BC = window blinds closed, BO = window blinds open.

7.4 Discussion

Minimal UVA signal was detected at any workstation. A large variation was seen in blue light measured at workstation 1, particularly during winter measurements where the solar elevation angle is lower and nearer the line of sight of the simulated eye position. It can also be seen that the blinds do not efficiently block sunlight. This is explained on examination of the blinds as the material is not solid and contains multiple small holes in each horizontal slat. Additionally, the degree of cloud cover is likely to have caused fluctuations between measurements. Although conditions were observed to be mainly clear, cloud may have obscured or partially obscured the solar disc at the point of automated data collection.

All calculated doses were well within ICNIRP guideline limits for UVA and blue light hazard exposure for the office environments measured. Unsurprisingly, calculated doses for blue light hazard are significantly lower in the office compared to flight deck environment. However, on aircraft with good UVA attenuating windshields, UVA dose for pilot and office worker are comparable. The pilots on flight 4, measured over the 9 hour 48 minute flight duration, received a calculated 0.22 ICNIRP dose while office workers over an 8 hour period would receive a UVA dose of between 0.19 to 0.28. Flight 3 was 4 hours 54 minutes including turn around and pilots received 0.15 ICNIRP dose. The pilots employed by the airline flown for data collection were rostered for a two sector flight. It is possible that other airlines may schedule pilots to fly a three or four sector shift depending on flight duration (section 10.5); however it is clear that ICNIRP guidelines are not exceeded when operating an aircraft with good UVA attenuating windshield properties.

The S-92a helicopter also showed good UVA attenuating properties. Helicopter pilots operating to North Sea oil platforms are more likely to undertake four sectors (two return flights) per working shift. The two flights on which data were collected showed calculated doses of 0.10 and 0.03 ICNIRP dose, comparable with the office worker and pilot operating an airline transport aircraft with good UVA attenuating windshields.

7.5 Summary

It is unsurprising that the calculated ocular dose for the office worker fell well within ICNIRP limits. It is recognised that these exposure calculations assume no solar eye protection, which is likely for an office worker. The results in chapter 4 describe the prevalence of sunglass use in pilots.

8. Chapter 8 Windshield and visor ground transmittance measurements

CHAPTER OVERVIEW

This chapter will describe the results of transmittance measurements taken through front and side aircraft windshields in addition to transmittance measurements through front visor and side window blinds. These data are captured whilst the aircraft is parked at a stand. Comparison of the various aircraft assessed particularly with regard to the UVA attenuating properties of the front windshields will be made. Limitations of these data will be discussed. Further data are presented regarding the prevalence of windshield failures during flight. Optical transmittance data from manufacturers and the windshield replacement schedule for aircraft will also be discussed.

8.1 Introduction

In flight irradiance data from flights 2 and 3 showed that there was a large difference in UVA measured (see section 6.3.1). Other factors influencing irradiance such as aircraft type, time of day, time of year, weather conditions, altitude and route were similar for both flights. The difference in UVA irradiance measured was found to be due to differences in the UVA attenuating properties of the two windshields.

As the type of windshield had a marked effect on pilot exposure to UVA, it was decided to take a series of transmittance measurements from both side and front windshields of a number of aircraft. This could be most efficiently achieved by taking measurements while the aircraft was on the ground. Taking ground measurements would have the additional advantage of ascertaining the transmission properties of any visors or blinds fitted in the aircraft.

8.2 Method

Two airlines (not previously taking part in the study) were approached and, following discussions, agreed to allow access to aircraft at the stands at London Heathrow (British Airways) and Exeter (FlyBE) airports. The same optical components as used for in flight measurements (Ocean Optics CC-3-UV diffuser, QP600-2-UV/BX 2 metre optic fibre cable and INLINE-TTL-S optical shutter powered by a YSN-12680 12V DC battery) were used. A series of spectral data were collected using the SpectraSuite software. This software was installed on a Toshiba Tecra M10-10I laptop with Windows XP operating platform. During practice data collection, it was found to be faster for the user to adjust integration times and save data using this machine compared with the smaller ASUS R2E palmtop. Time constraints were an important consideration as an aircraft cockpit was often only available for a short period of time between flights. Additionally, being able to efficiently collect data from aircraft was thought important to encourage airline personnel to cooperate in allowing access to further aircraft.

A representative from the airline escorted the researcher to the various aircraft. During data collection, they were instructed on how and where to hold the probe while the researcher adjusted the integration time to give an optimum signal. A maximum signal of between 14,000 to 15,000 counts was chosen to give a strong signal which was not saturated. Each spectrum was saved as a tab delimited text file readable in Microsoft Excel.

Measurements were taken with the probe in the following positions:

1) Facing forward within 5cm of right windshield
2) Facing forward within 5cm of left windshield
3) Outside facing forward at the same fore/aft position with probe held out of open side window.
4) Facing forward within 5cm of a deployed front right visor
5) Facing forward within 5cm of a deployed front left visor
6) Facing toward right side window within 5cm of inside surface
7) Facing toward right side window with side blind deployed and within in 5cm of surface
8) Facing toward left side window within 5cm of inside surface
9) Facing toward left side window with side blind deployed and within in 5cm of surface
10) Dark measurement

Data were collected on 6 November 2012 (London Heathrow), 16 April 2013 (London Heathrow) and 28 August 2013 (Exeter). On each occasion, weather conditions were dry with some scattered cloud cover present. No illuminance UV recorder data were collected. Following agreement from Brooklands Museum, Weybridge, ground measurements were also captured from the Concorde at the museum on 25 June 2013 when weather conditions were dry and sunny. Additionally, ground measurements were taken on flights 5 and 6 during turn around at Alicante and Rhodes respectively. Here, data were collected using the ASUS R2E palmtop.

All data were analysed using Microsoft Excel 2007. Transmittance data were calculated by subtracting the appropriate dark reading from each spectral measurement and using integration time to calculate the counts per second (cps) value for each wavelength step from around 200 – 1100nm. Front and side windshield transmittance was then expressed as a percentage value of the equivalent wavelength step cps values from the outside (source) measurement.

To calculate the transmission properties of visors and blinds, the cps values were calculated and were expressed as a percentage value of the equivalent wavelength step from the inside data captured behind the particular window without the visor or blind in place.

8.3 Results

Transmittance data were collected from 15 aircraft of various aircraft types including Boeing (B747, B757, B777), Airbus (A320, A321), Embraer (195) and Bombardier (Dash8). Outside measurements were not possible from B747 as there are no opening side windows fitted on this aircraft. The pilots' emergency exit on this aircraft type is a hatch situated in the roof of the cockpit. Opening side windows were also not available on Concorde and Dash8 aircraft. Here, measurements were taken on the ground to the side of the aircraft at the same fore/aft position as the windshield.

Full transmittance data were not used for all aircraft tested. This was due to the peak transmittance values found for some measurements. As the source was the outside measurement and was taken at one point during each aircraft data collection, it is recognised that this signal may not be stable throughout the measurements taken on each aircraft due to partial cloud cover. Additionally, where the signal is weaker due to cloud cover or low UV due to time of year, a lower signal to noise ratio is present which leads to increased uncertainty of data.

For all windshields, it was possible to ascertain the point at which a UVA signal was detectable (Table 8-a and Table 8-b). Aircraft number 4 was also used for in-flight measurements on flight 5 and aircraft number 15 was used for flight 6. The windshields all fell into one of two distinct categories. Due to the uncertainties described above, windshields are described as either good or poor UV attenuators.

						UV attenuation			
Aircraft No.	**Type**	**Built**	**Airframe hrs**	**as of**	**measured on**	**R front**	**L front**	**R side**	**L side**
1	B777-200	2000	48780	31/12/2011	06/11/2012	poor	poor	poor	poor
2	B747-400	1993	89575	31/12/2012	06/11/2012	good	good	good	
3	B777-200	1999	54961	31/12/2011	06/11/2012	poor	poor		
4 (used on flight 5)	A321-200	2004	23440	31/12/2011	01/03/2013	poor	poor	poor	good
5	B777-300	2011	919	31/12/2011	16/04/2013	poor	poor	good	poor
6	B777-200	1998	66296	31/12/2012	16/04/2013	poor	poor	poor	poor
7	B777-200	1997	62462	31/12/2011	16/04/2013	poor	poor	good	good
8	B747-400	1991	90272	31/12/2011	16/04/2013	good	good	good	good
9	B777-200	1998	61318	31/12/2011	16/04/2013	poor	poor	poor	good
10	B747-400	1990	101859	31/12/2011	16/04/2013	good	good	good	good
11	A320-200	2007	10703	31/12/2011	16/04/2013	poor	poor	good	good
12	Concorde	1973	not available		26/06/2013	good	good	poor	
13	Embraer 195	2008	8413	31/12/2012	28/08/2013	poor	poor	good	good
14	Bombardier Dash	2005	12195	31/12/2011	28/08/2013	good	good	good	good
15 (used on flight 6)	B757-2T7	1987	91829	31/12/2012	21/08/2013	poor	poor	good	good

Table 8-a Summary of aircraft used for ground measurements together with the windshield UVA attenuation properties. Good UVA attenuation is where a signal is detectable from around 400nm. Poor UVA attenuation is where a signal is detectable from around 365nm.

Helicopters flown for flight	**Type**	**Built**	**Airframe hrs**	**as of**	**measured on**	**R front**	**L front**
7	AS332L	1984	37312	31/12/2012	09/04/2013	poor	
8	AS332L	1982	39293	31/12/2011	09/04/2013	poor	poor
9 & 10	S-92A	2011	7	31/12/2011	10/04/2013		good
Aeroplanes flown for flight							
1 & 2	A320-200	2001	37526	31/12/2012	16/05/2012		poor
3	A320-200	1994	69461	31/12/2012	26/05/2012		good
4	A330	1999	63,637	21/11/2012	21/11/2012	good	

Table 8-b Summary of additional data captured from aircraft used for in flight measurements. Good UVA attenuation is where a signal is detectable from around 400nm. Poor UVA attenuation is where a signal is detectable from around 365nm.

A total of 140 spectral measurements were taken including outside (source) measurements. Of these, full spectral data from 64 files were excluded due to peak transmittance values. This is discussed further in section 8.5.

Figure 8-a shows transmittance curves from the left front and side windows from aircraft 6, a Boeing 777 together with the transmittance curves of the left front visor

and side blind. This is an example of an aircraft with poor UVA attenuating front and side windows.

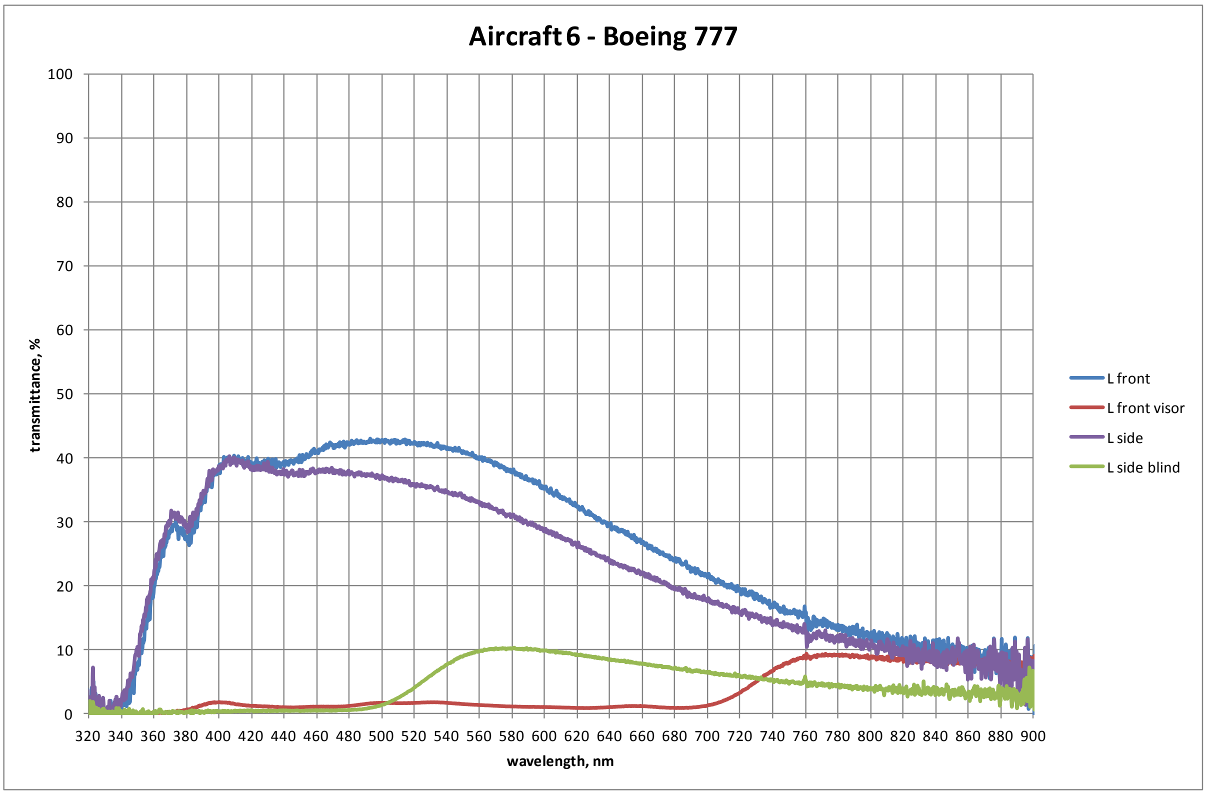

Figure 8-a Summary of transmittance measurements from aircraft 6.

Figure 8-b and Figure 8-c show transmittance curves from aircraft with good UVA attenuating windshields. Figure 8-b shows transmittance of left front and side windows from aircraft 14, a Dash8, together with the transmittance curves of the left front visor. Figure 8-c shows transmittance of right front and side windows from aircraft 10, a B747, together with the transmittance curves of the corresponding visor and side blind. Outside (source) data applied was from outside aircraft 11 taken approximately 30 minutes after measurement on aircraft 10.

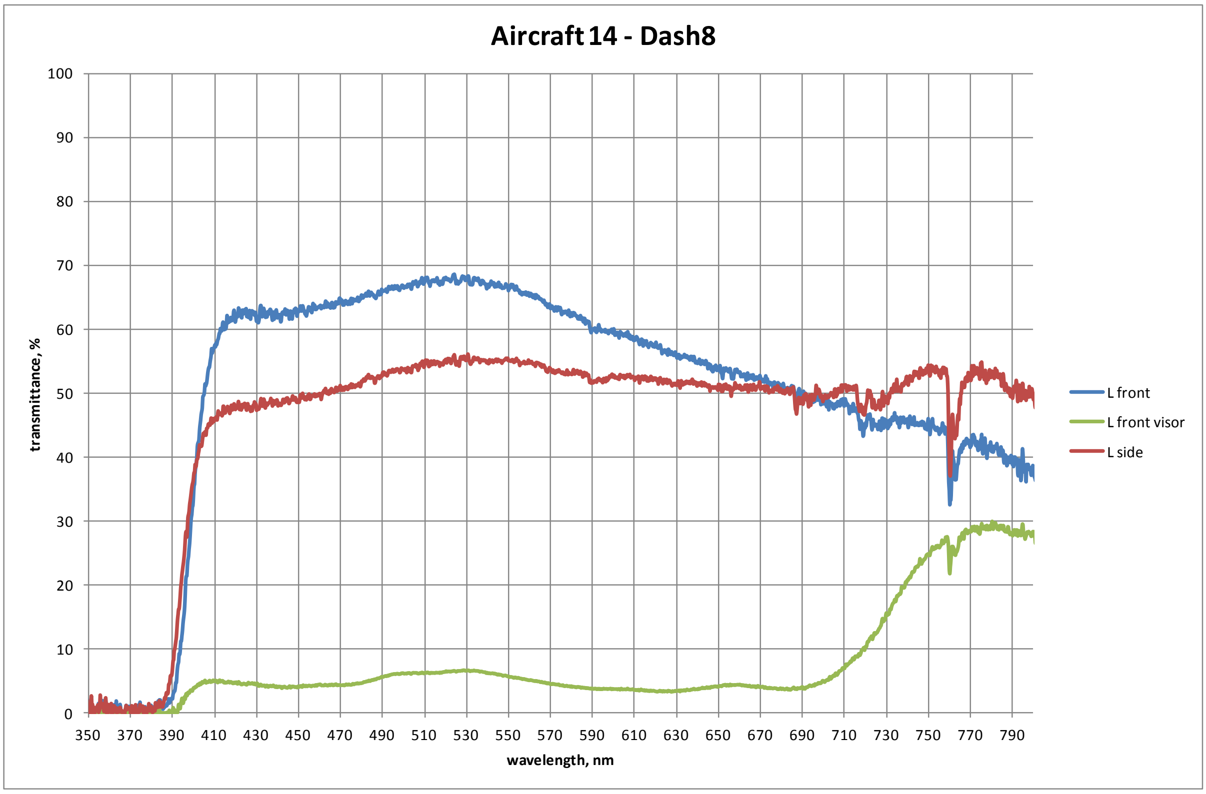

Figure 8-b Summary of transmittance measurements from aircraft 14.

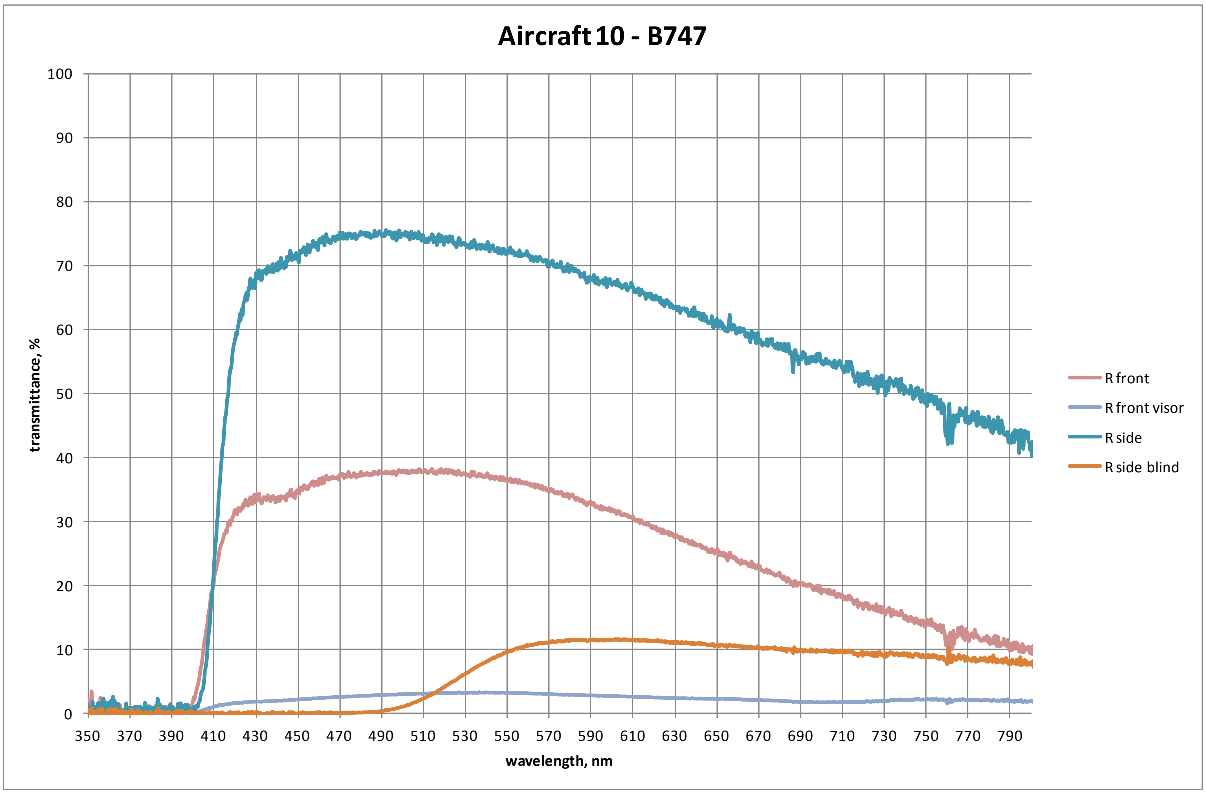

Figure 8-c Summary of transmittance measurements from aircraft 10.

Figure 8-d and Figure 8-e show the transmission properties of aircraft with poor UVA attenuating front windshields but with a good UVA attenuating side window.

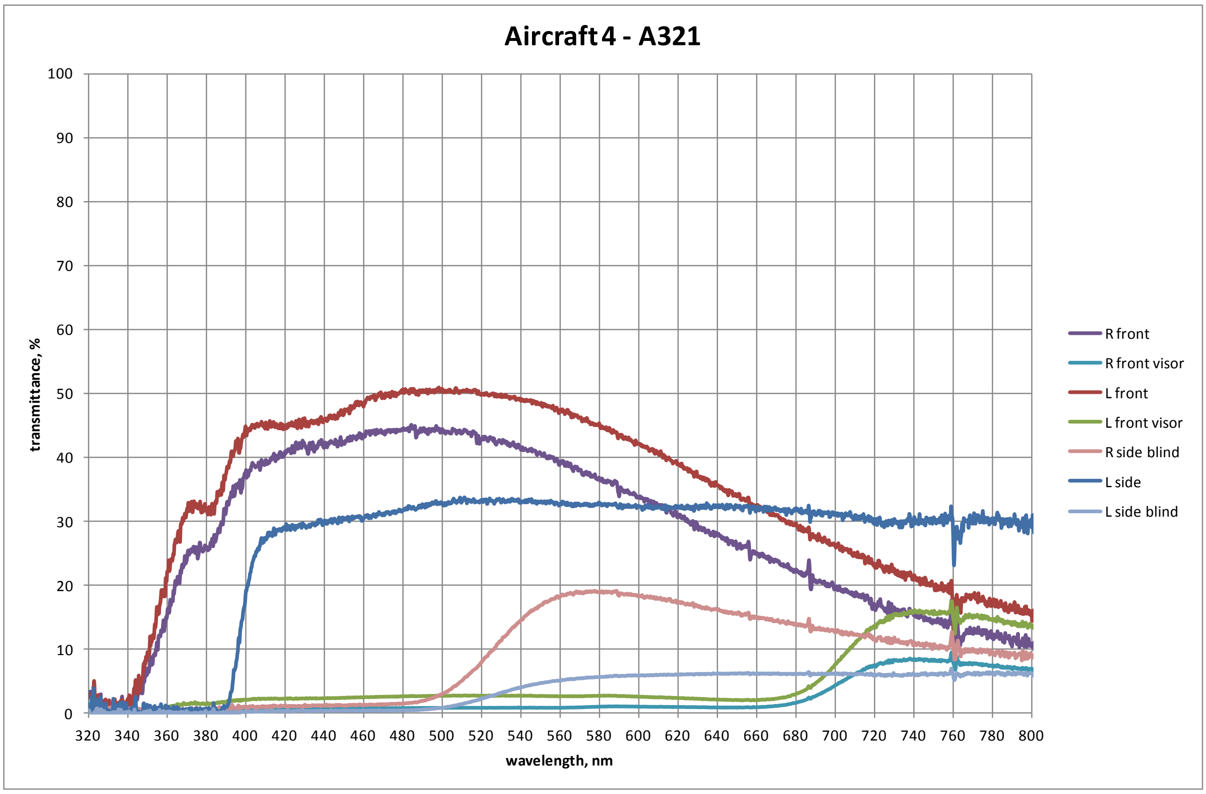

Figure 8-d Summary of transmittance measurements from aircraft 4.

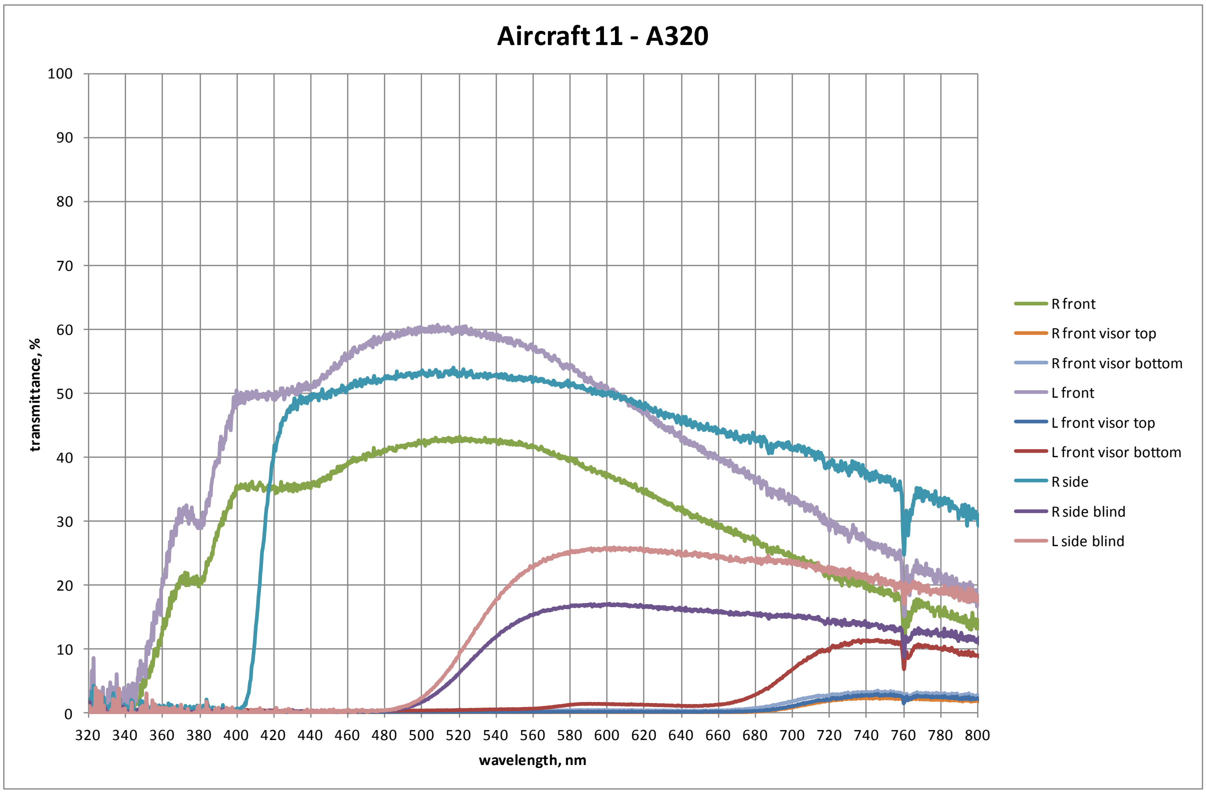

Figure 8-e Summary of transmittance measurements from aircraft 11.

Figure 8-f shows the transmission properties of an aircraft with poor UVA attenuating front windshields and with one good and one poor UVA attenuating side window.

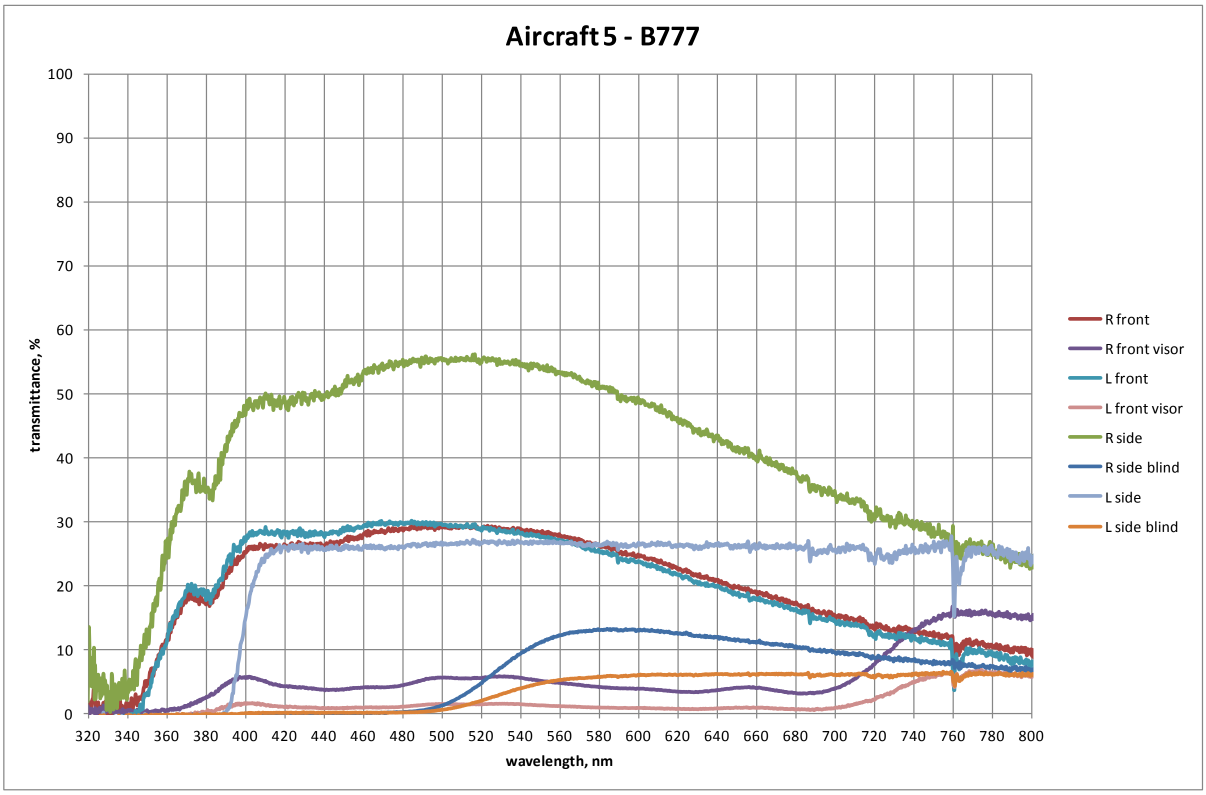

Figure 8-f Summary of transmittance measurements from aircraft 5

Figure 8-g shows a further example the transmission properties of an aircraft with poor UVA attenuating front windshields but with a good UVA attenuating side window. Additionally, transmittance measurements were captured through a Head-Up Display (HUD) fitted for the captain of the aircraft (left hand seat). The HUD had a dedicated fitted visor which was also measured.

Figure 8-h shows the results of the measurements taken from Concorde. The nose cone was in the raised position as would have been during cruise flight, thus front transmittance measurements are a result of attenuation through two separate windshields.

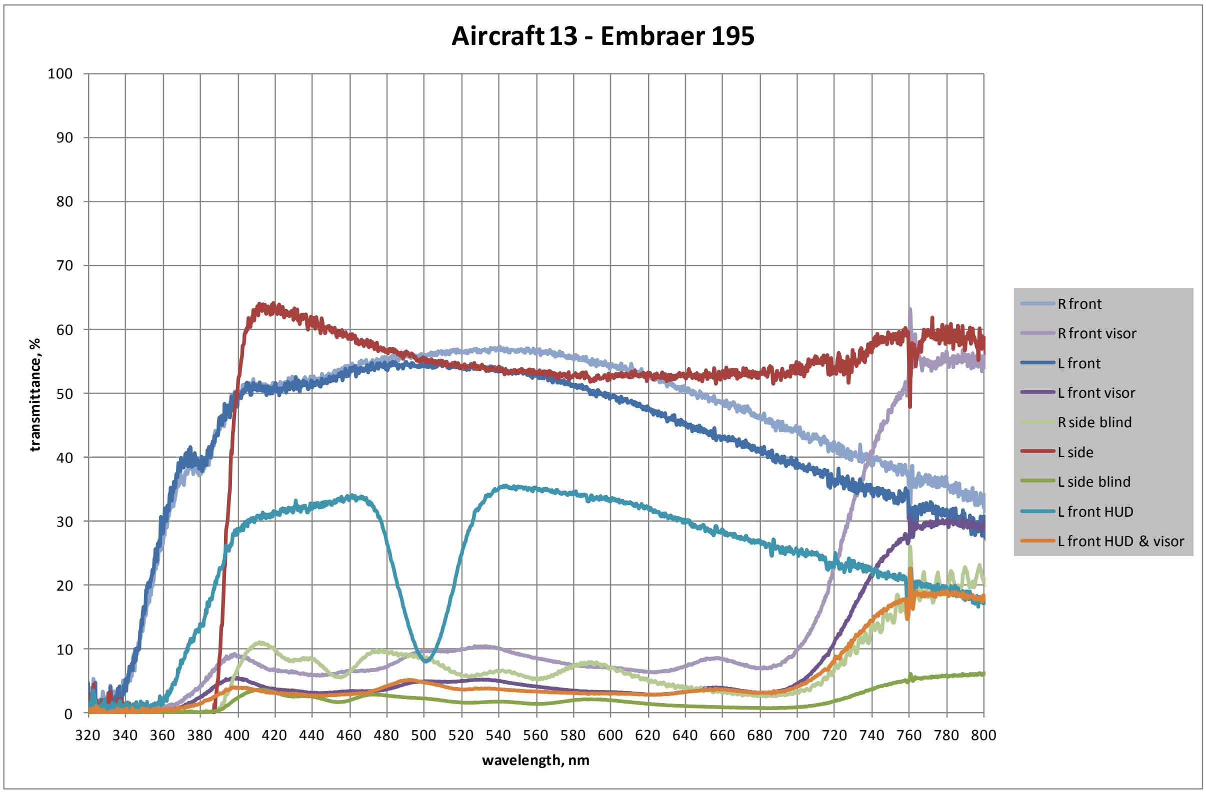

Figure 8-g Summary of transmittance measurements from aircraft 13. HUD = Head Up Display.

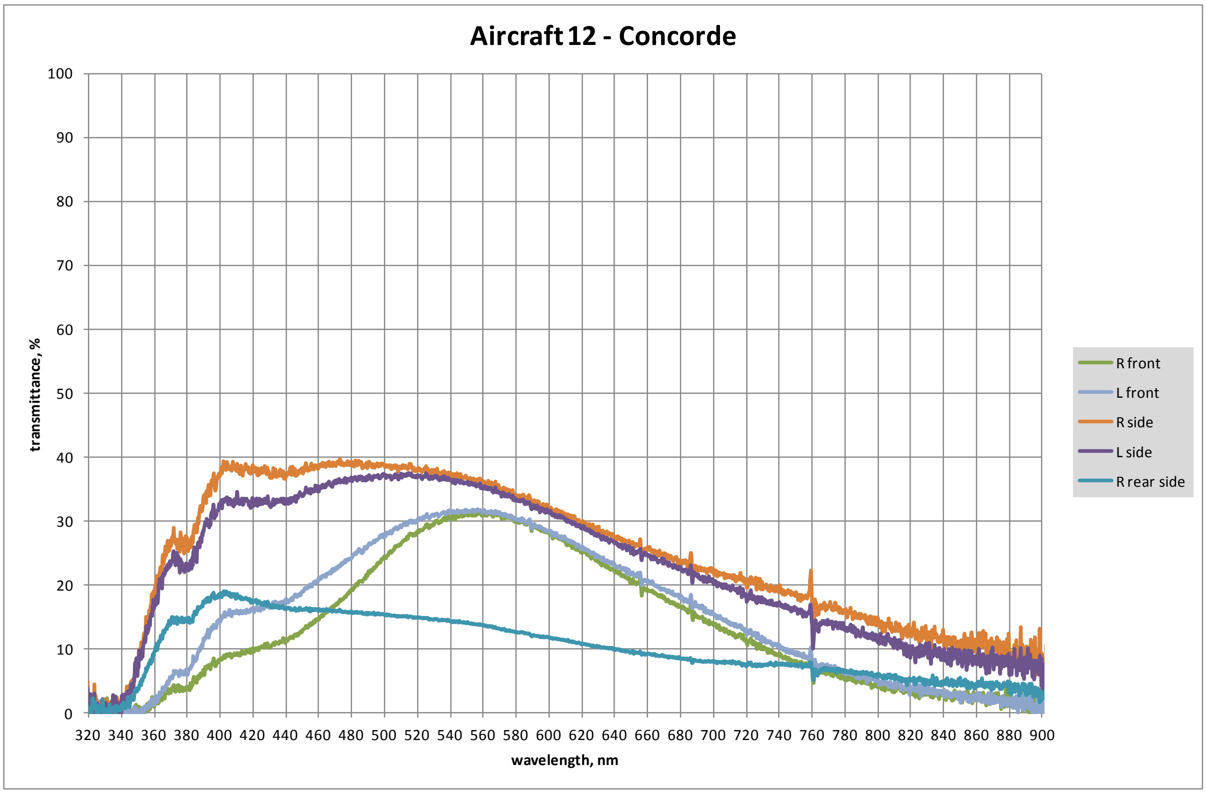

Figure 8-h Summary of transmittance measurements from aircraft 12.

8.4 Discussion

Aircraft windshields are generally thick and constructed of multi-laminate glass. A heating element layer composed of gold thread is present and the windshield is constructed to withstand impact, high cyclical temperature loads and cabin pressurisation. A small percentage of incident light will be reflected at each laminate surface. It will therefore be expected that a higher proportion of incident light will be reflected compared to a single layer pane of glass. Additionally, the cleanliness of the windshield will affect the signal received at the spectrometer. These factors together with potential variations in outside signal and direction of the diffuser (discussed in section 8.5) are likely to affect the peak transmittance curves measured.

8.4.1 Front windshield transmittance

Of the aeroplanes measured currently registered (n=17 including those where measurements were taken in flight), 5 (29%) would be considered to have good UVA attenuating front windshields. The aircraft show a wide range of age from a Boeing 777-300 registered in 2011 to a Boeing 757 registered in 1987. It is interesting to note that the oldest registered aircraft measured were the three Boeing 747s (registered 1990, 1991 and 1993) the Airbus A320 (1994) and the Boeing 757 (1987). Of these five aircraft, all have good UVA attenuating front windows with the exception of the Boeing 757. Additionally, the decommissioned Concorde built in 1972 showed better UVA attenuating properties than many of the newer aircraft. British Airways (who operate the three Boeing 747s measured) plan to replace the B747 fleet with new B787 Dreamliner aircraft.

Information gained from pilots and airline engineering departments revealed that there is no scheduled replacement of windshields. Although the fixings to secure the windshield in place are replaced, the windshield itself is inspected and replaced when damage such as cracks or de-lamination occurs. Information was requested from the airlines of the windshield replacement history, if any, on various aircraft. Although this information would be retained, it was not possible to access this for the purposes of this study. However, it seems probable based on the data, that newer aircraft have poorer UVA attenuating windshields fitted. It is suspected that the aircraft 15 (Boeing 757) has, at some point, had replacement front windshields fitted.

Based on the data, it would seem likely that the proportion of current registered aircraft with good UVA attenuating properties will decrease over time as older aircraft are taken out of service or have replacement windshields fitted.
All aircraft measured showed similar UVA attenuating properties for left and right windshields. It could be argued that if windshields were replaced routinely, there could be a higher probability that the left and right front windshields would show different transmission properties.

No additional ground measurements were taken from helicopters other than those that flew with the spectrometer. There is therefore limited data available, however a recently manufactured (2011) Sikorsky helicopter showed good UVA attenuating windshields due to the acrylic glass laminate windshield fitted (see section 6.3.1) while the older Aerospatiale aircraft had poor UVA attenuating windshields. It is not known the properties of new Aerospatiale aircraft windshields.

8.4.2 Side window transmittance

A higher proportion of side windows measured demonstrated good UVA attenuating properties. All aircraft with good UVA attenuating front windshields had side windows with similar properties. An additional four aircraft had both side windows with good UVA attenuating properties but with front windshields with poor UVA attenuating properties. Further, three aircraft demonstrated one poor and one good UVA attenuating side window together with poor UVA attenuating front windshields. This was the case on a relatively new aircraft built in 2011 (aircraft no 5). It is not known what, if any, replacement schedules are in place for side windshields.

8.4.3 Front visor transmittance

Boeing front visors showed low transmittance (3-4%) of wavelengths below 700nm. Aircraft 5 and 6 (both B777) show a slight increase in transmittance beyond 700nm to around 10% while aircraft 10 (B747) and 15 (B757) remain at around 3% beyond 700nm. This may be due to a different material or tint used for these visors. Aircraft 10 (1991) and 15 (1987) were older than aircraft 5 (2011) and 6 (1998) and this difference may represent a modification to Boeing visor manufacture between 1991 and 1998 or may be due to changes to the transmission properties of visors with age.

The front visors on aircraft 4 (Airbus A321) show minimal transmittance from 400nm and increase in transmittance around 680nm to between 9% (right visor) to 15% (left visor). Following ground measurements of aircraft 4, it was discovered that front visors from Airbus A320/A321 had a slight graduation of visor tint. It is therefore feasible that the two front visor measurements were taken from different relative points on the visor. Transmittance data from aircraft 11 (Airbus A320) also show minimal transmittance up to around 680nm however increased only to 2-3% transmittance at the top of the visor and around 11% at the bottom of the visor. Aircraft 13 (Embraer 195) showed a low transmittance (around 5%) throughout the visible spectrum from both visors. Aircraft 14 (Dash8) shows a consistent transmittance of around 5% for the front visor throughout the visible spectra. Aircraft 4, 5, 6 and 13 all have poor UVA attenuating front windshields. The front visors all show a signal detected below 400nm. Therefore the front visors fitted in these aircraft do not provide complete UV attenuation.

Additionally, aircraft 13 had a HUD which selectively blocks wavelengths around 500nm. The placement of the dedicated HUD visor provides similar blocking properties to the front visors and also does not appear to provide total UV attenuation.

8.4.4 Side blind transmittance

The transmittance of the side blinds show aircraft 4 (Airbus A321), 5 and 6 (Boeing B777s), 10 (Boeing B747) and 11 (Airbus A320) have similar transmission blocking properties, transmitting around 2% of wavelengths below around 500nm increasing to around 10% transmittance at 560nm and remaining between 5-10% transmittance for the rest of the visible spectrum. No detectable signal was seen below 400nm. This was the case in side blinds measured in front of both good and poor UVA attenuating side windows. Aircraft 5 was found to have a good UVA attenuating left side window and a poor UVA attenuating right side window, yet minimal transmittance of wavelengths below 500nm was found with both side blinds.

Aircraft 13 showed a low transmittance (around 5%) throughout the visible spectrum through the side blinds. It cannot be ascertained whether the side blinds transmit below 400nm as this was effectively blocked by the side windshields in front of which they were measured.

8.5 Limitations of data

Due to the potential variation of a solar reference source under which measurements took place, care must be given to detailed interpretation of the degree of absorption particularly of fitted visors and blinds in the aircraft. Additionally, it is recognised that measurements through side windows and blinds were taken with the diffuser head at a different angle to the outside reference measurement. This may have also affected the accuracy of peak transmittance values. Transmittance measurements of visors and blinds are affected by the transmission properties of the windshield behind. It is likely that due to the multilayer nature of the windshields, at least 20% of incident light would be lost due to reflection.

Consideration was given to adjusting all windshield transmittance data to a common peak transmittance. By carrying this out, more of the data could be assessed. However due to the assumptions required, the accuracy of the degree of transmittance of the blinds and visors could be challenged. For this reason, data that were considered unfeasible were not used. This occurred for example, where windshields were calculated to have transmittance over 100%. This was most likely due to changing ambient light levels being higher at the time of windshield measurement compared to when the outside measurement was captured or, as described above, where the diffuser head was pointing in a different direction to the reference measurement.

8.6 Windshield information

8.6.1 Data from manufacturers (aircraft and windshield)

Numerous contacts were made with aircraft manufacturers (Airbus and Boeing) and identified windshield manufacturers. Information was requested for any technical information of the optical transmission properties of windshields made or installed. Despite attempts, no information has been provided. It is suspected that this may be considered proprietary information and viewed by the companies as their own property and not appropriate for public release.

8.6.2 Mandatory Occurrence Reporting Scheme data

The CAA manages the Mandatory Occurrence Reporting Scheme (MORS) which applies to any aircraft operated under a UK Air Operators Certificate and any turbine-powered aircraft with a Certificate of Airworthiness issued by the CAA. A reportable occurrence in relation to an aircraft means any incident which endangers or which, if not corrected, would endanger an aircraft, its occupants or any other person.

Voluntary reports related to any aircraft are encouraged and treated in the same way as a mandatory report. The reporting requirement also applies to any United Kingdom ground facilities or services provided for such operations. Incidents of windshield damage or failure in flight should be reported under MORS. Therefore a database search was requested of the number of windshield incidents reported between 1 January 2010 to 31 December 2013 on passenger turbo-prop and jet aircraft. Incidents involving business jet aircraft were excluded.

A total of 75 incidents were reported which mainly involved damage to the outer windshield layer. Incidents normally involved damage to one windshield and involved front or side windows. Airline statistics data, held by the CAA (CAA, 2014) revealed a total of 977 UK registered commercial passenger aircraft being operated in November 2013. Assuming all incidents are reported, this represents a risk of a particular aircraft having a windshield failure during flight at 1.9% risk per annum or 1 windshield failure per aircraft every 52 years. The total number of flying hours flown during the whole of 2013 was 7.9 million hours which gives an incident rate of 1 every 420,500 hours.

It is not clear whether all of these incidents would trigger a replacement windshield to be fitted or whether repair could be carried out to minor damage. Additionally these data do not include cases of windshield replacement triggered through inspection at routine maintenance checks.

Examination of the 75 cases reported revealed that the aircraft used for flight 1 and 2 suffered a crack to the outer pane of the right hand windshield on 13 February 2010 (before data collection was undertaken). Spectrometer data collection was conducted behind the left windshield for both flights. Additionally, aircraft 2 used for ground measurements reported a “*shattered nr3 window behind First Officer*” during flight on 31 January 2011. This also occurred before data collection; however it is thought that the window involved was the furthest (aft) side window from the pilot and not the fore side window used for transmittance measurement.

8.7 Summary

The results of this chapter show that most of the oldest aircraft assessed had good UVA attenuating windshields whilst all of the most recently registered aircraft had poor UVA attenuating windshields. There was no correlation observed between the aircraft manufacturer or aircraft type and the UVA windshield attenuation properties. Indeed, aircraft measured of the same type showed different windshield attenuation properties. Whilst no data was available from manufacturers, the evidence would indicate that a windshield failure during flight is a rare occurrence and that windshields are replaced at maintenance assessments only when there is evidence of damage to the windshield or to the windshield fixings.

The results show that all side window blinds offer good UVA blocking properties however a number of front visors demonstrated higher transmittance of UVA. All visors and blinds showed effective attenuation of visible light.

Limitations of the data include the potential for inconsistency of output of the solar source and a low UV signal due to cloud cover. Some data were discarded due to this. Additionally, transmittance measurements of visors and side blinds are restricted by the filtering of the windshield however comparison is offered in chapter 9 using a similar front visor measured in more controlled conditions.

9. Chapter 9 Sunglass Transmittance Measurements (Phase 3)

CHAPTER OVERVIEW

This chapter describes the results of used and new sunglass filter transmittance measurements and forms phase 3 of the research previously described in chapter 3. Particular attention is paid to the sunglass filtering properties within the UVA range and at the peak of the blue light hazard. Data limitations and exclusion criteria for used sunglasses are discussed. Comparison between right and left filters, new and used filters and clean and marked filters is made. Additionally, an assessment of compliance to ISO with regard to solar UVA transmittance is undertaken on a small selection of sunglasses.

9.1 Introduction

As with irradiance measurements, the assessment of sunglass transmittance requires specific equipment for accurate measurement. Spectrometers are commonly used for material transmittance measurements (ISO 12311, 2013). The same considerations regarding accuracy and reliability of the spectrometer and associated optics apply as for irradiance measurements.

The primary objective of phase 3 was to assess the lens transmittance properties of typical sunglasses used by pilots. As recognised in sections 1.10 and 2.4, a degree of peripheral radiation beyond the edge of the sunglass frame may be present and could contribute to the overall ocular irradiance. Measurement of transmittance through the sunglass filter does not account for this factor. If this aspect were to be addressed, it would be most effectively simulated in laboratory conditions rather than field measurements. A series of sunglasses could be fitted to a manikin head with a cosine corrected head placed in the eye position. A light source could be adjusted to various incident angles to the manikin eye and spectral measurements taken with and without sunglasses fitted. However, the fitting of sunglasses to a manikin head does not take into account the anatomical variation in the pilot population and may not provide results that could be transferable to sunglass fitting guidelines. It was decided that, due to this and to the additional amount of data that would be generated, that measurements of peripheral radiation would not be included in this research.

The Ocean Optics spectrometer used is a single beam instrument therefore, separate measurements are required with and without the sample in place. A double beam instrument would allow simultaneous readings to be taken and would be considered more accurate (ISO 12311, 2013), however would not have offered the portability of a single beam instrument. In order to take measurements, a known light source with a stable output over time should be used. Ideally, this lamp should contain an optical shutter so that measurements of background noise can be taken. Radiation from the lamp should be collimated and the distance between lamp and spectrometer collimating lenses kept to a minimum to prevent significant loss of signal. Collimating lenses must be accurately aligned and steps taken during measurement to ensure that the beam is not displaced across the measurement zone.

The aim was to measure a small selection of sunglasses typically used by pilots. The typical sunglass types are known through the results of the questionnaire. It was considered that used pilot sunglasses should primarily be measured as this would produce data of the attenuation properties of sunglasses (including old or damaged lenses) used in flight. However, it was also recognised that these used sunglasses may represent different properties from their new equivalents. Whilst acknowledging that there is a large choice for the consumer in sunglass models, it was aimed to gain measurements from 15 used and 10 new appropriately selected sunglasses of the types typically used by pilots.

9.2 Description of equipment

The HR4000 Spectrometer (described in chapter 5) was used for this phase of the project. The optics used differed from previous data collection phases. An Ocean Optics DT-MINI-2-GS with combined deuterium and tungsten halogen light sources and a constant relative spectral power distribution throughout the UVA and visible range was used. The unit had a shutter switch allowing dark measurements to be taken without turning the lamp off. The lamp was connected to a metal sleeved QP600-2-UV/BX 2 metre optic fibre cable which was in turn connected to an Ocean Optics 74-UV collimating lens. These lenses are adjustable and are set at the time of manufacture to provide collimated light from a 600µm optic fibre. The lenses have a screw thread which enables them to be secured to an Ocean Optics Adjustable Collimating Lens Holder. This holder (Figure 9-a) allows a pair of collimating lenses to be installed at a chosen equal height directly in line with each other. The distance between the collimating lenses can be adjusted by Allen key at the base and moving each vertical post along its sliding base.

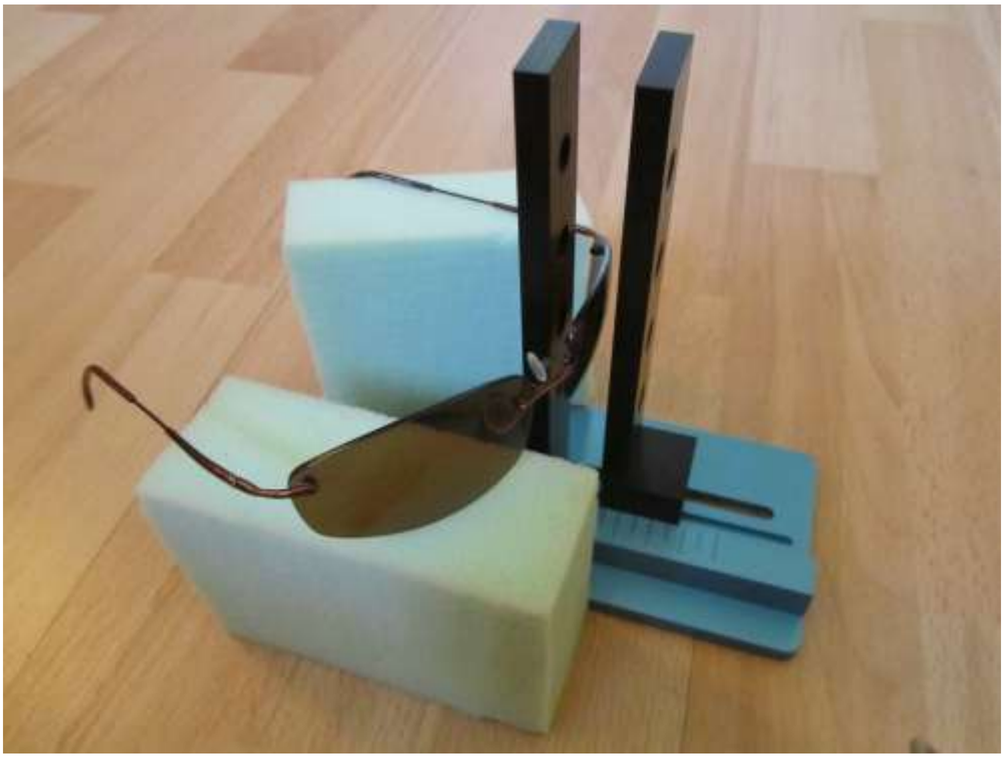

Figure 9-a Ocean Optics adjustable optical bench showing four matched height options for securing collimating lenses. Foam blocks were available to assist stable sunglass placement.

A series of foam blocks were available to position the sunglass lens as shown in Figure 9-a. A large piece of fabric blackout material was also available. The second Ocean Optics 74-UV collimating lens was connected to another QP600-2-UV/BX 2 metre optic fibre cable which was connected to the HR4000 unit. As the light source unit had an inbuilt shutter, the Ocean Optics INLINE-TTL-S optical shutter was not required.

The HR4000 unit was connected to the Toshiba Tecra M10-10I laptop used for ground transmittance measurements in chapter 8. SpectraSuite software was used for data collection.

9.3 Method

9.3.1 Pilot sunglasses

An airline with a large base at London Gatwick was contacted. A request was submitted to visit the crew rooms in order to collect transmittance data from used pilot sunglasses. This was agreed by the airline and the researcher together with two colleagues from PHE collected data on 8 July 2013.

Crew rooms are used by the flight crew mainly before but also after flight. The flight crew are normally present for around 30 minutes before departing for the aircraft in order to conduct pre-flight planning. The proposal was that the pilot would, if willing to participate, loan their sunglasses for measurement while conducting their pre-flight planning. The researchers then would take measurements from the sunglasses and return them to the pilot. The airline informed the staff of the visit prior to the date and information sheets (appendix P) were placed around the crew room on the date of data collection in order to promote participation.

A representative from a manufacturer of pilot sunglasses (Bigatmo) was additionally a professional pilot for the airline approached for sunglass measurements and contacted the researcher prior to the date of data collection. Following discussion, it was agreed that he would also attend during data collection with new samples of Bigatmo sunglasses for measurement.

Details were taken of each pair of sunglasses including make and model (usually available on the inside surface of one of the spectacle frame sides), details of whether the lenses were known to be photochromic, prescription, polarised or graduated tints and predominant tint colour based on visual inspection. These details were stored in a separate Microsoft Excel spreadsheet.

The light beam emitted from both collimating lenses was visually assessed for even intensity and uniformity against a piece of white paper. Reference spectra from the source together with dark measurements were taken at the start and end of the data collection session. To ensure that the data would not be affected by the surrounding ambient light, blackout material was sourced. However, when assessed on the day of data collection, it was found that the use of this material enclosing the area of the optical bench made no difference to the spectra (Figure 9-b). The data were therefore considered to be unaffected by the ambient light (the equipment was situated inside and with no natural daylight). The spikes seen represent hydrogen emission lines present from the deuterium component of the light source. Although this deuterium component allows a strong and consistent output throughout the UVB and UVA range, emission spikes within the visible spectrum are unfiltered (personal communication, Ocean Optics 23/06/14) and therefore contribute to the overall output which also includes the tungsten halogen component.

The lens holder was adjusted to ensure a minimum distance between collimating lenses yet to allow the sunglass filter to be safely positioned without damage. It was found that for speed of measurement, one researcher could hold the sunglasses in position and verbally confirm position to another researcher who took the measurement.

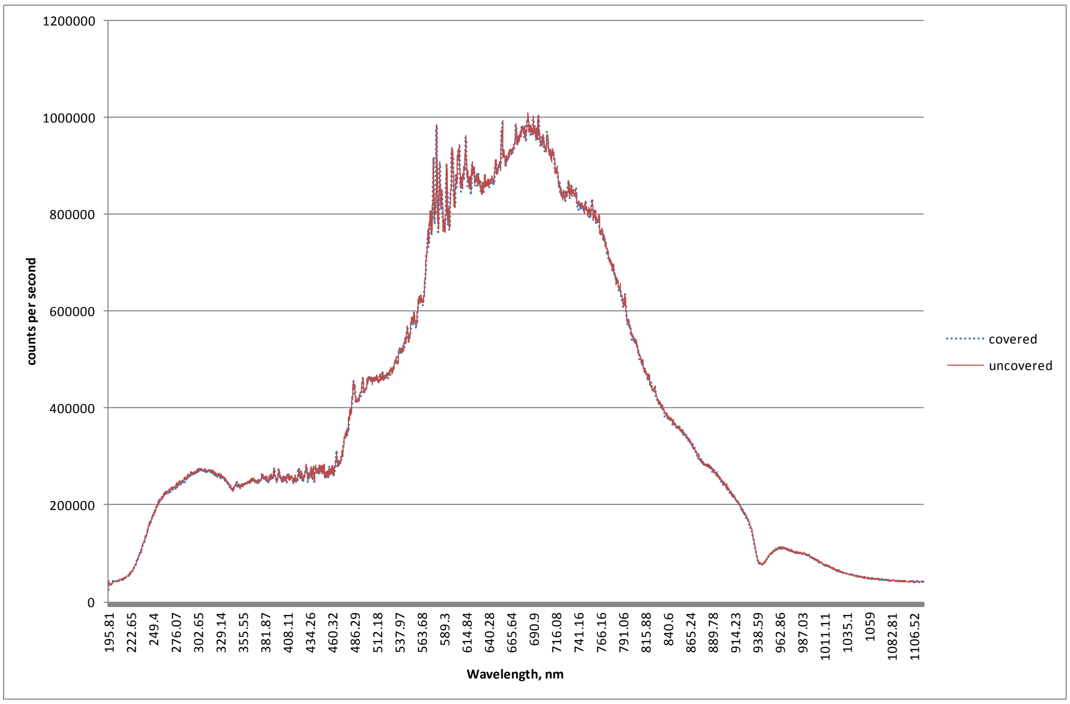

Figure 9-b Signal detected from Deuterium Tungsten Halogen light source with or without black out material over optical bench.

For each measurement, the researcher adjusted the integration time to give an optimum signal. A maximum signal of between 14,000 to 15,000 counts was chosen to give a strong signal which was not saturated (maximum count of HR4000 was 16,383). Each spectrum was saved as a tab delimited text file readable in Microsoft Excel.

The sunglasses were assessed for lens degradation (such as scratches) and cleanliness and this was recorded with the sunglass details. They were then placed at the estimated optical centre at a normal plane to the collimating lenses with the frame in a horizontal position. Measurements were taken from each lens of each pair of sunglasses. Where the sunglasses lenses were seen to be dirty, a second set of measurements were taken after cleaning the lenses with a lens cloth. It was not known whether the HR4000 would be sensitive to polarised light. Therefore, sunglass lenses known to be polarised were additionally measured with the sunglasses rotated so that the right and left lenses were as close to a vertical plane as practical.

Graduated tinted lenses were measured at three points on each lens. These were at the top for the maximum tint, at the bottom of the lens for the minimum tint and at the estimated optical centre. Photochromic lenses were measured in the reacted state in which they presented. The outside weather conditions were sunny and it is possible that some lenses were partially reacted when measured. A UV penlight became available during data collection and attempts were made to measure some lenses in a level of activation. The penlight was also used to determine whether a particular pair of sunglasses had photochromic properties.

Each pair of sunglasses had transmittance measurements taken from right and left lenses. A dark measurement was taken after completion of transmittance readings of each pair of sunglasses. Data collection from each pair of sunglasses typically took between one to four minutes. Stability of the output of the light source was assessed by capturing a spectrum at the start and end of data collection. This is shown in Figure 9-c for the new sunglass data collection session and shows a consistent output.

Data were analysed in Microsoft Excel 2007. Transmittance data were calculated by subtracting the dark reading from each spectral measurement and using integration time to calculate the counts per second (cps) value for each wavelength step from around 200 – 1100nm. These cps values were expressed as a percentage value of the equivalent wavelength step cps values of the source.

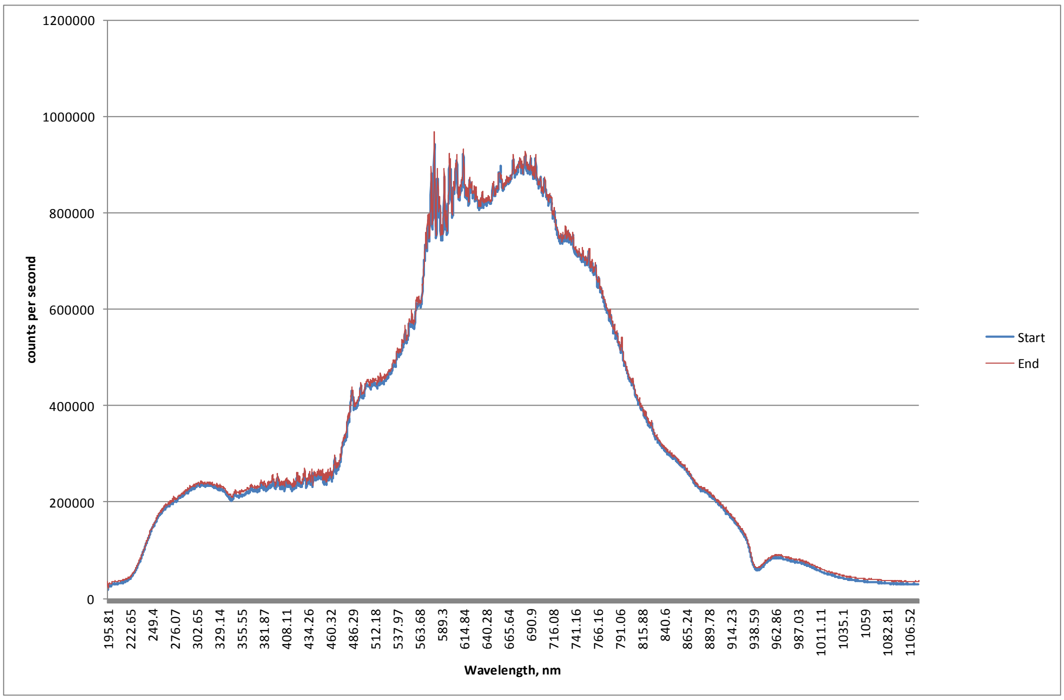

Figure 9-c Stability of Deuterium Tungsten Halogen light source. Output measured at start and end of data collection session.

9.3.2 New sunglasses

A local community based optometry practice was approached and agreed to allow the researcher to attend to capture transmittance data from a series of new sunglasses. This was carried out on 11 July 2013 and after the crew room data collection when equivalent models of the most prevalent sunglass types (mainly RayBan and Oakley) measured in the crew room could be assessed. Where possible, the same sunglass model was used. The equipment and protocol for measurement were the same as for the used sunglass measurements. No difference was found in the spectrum with and without the blackout material in place. Measurements were taken with the assistance of a member of staff at the practice holding the sunglasses in place using the same protocol as for the used sunglass measurements with the exception that measurements were generally collected from one lens. A dark measurement was taken after completing measurements from each pair of sunglasses.

9.4 Results

9.4.1 Comparison of right and left lenses

There was insufficient time available to assess the uniformity of filter luminous transmittance, however all used sunglasses had transmittance measurements taken from both lenses. For analysis purposes, the mean transmittance was used and differences in inter lens transmittance measured were minimal. Figure 9-d shows examples of used sunglass transmittance curves through right and left lenses.

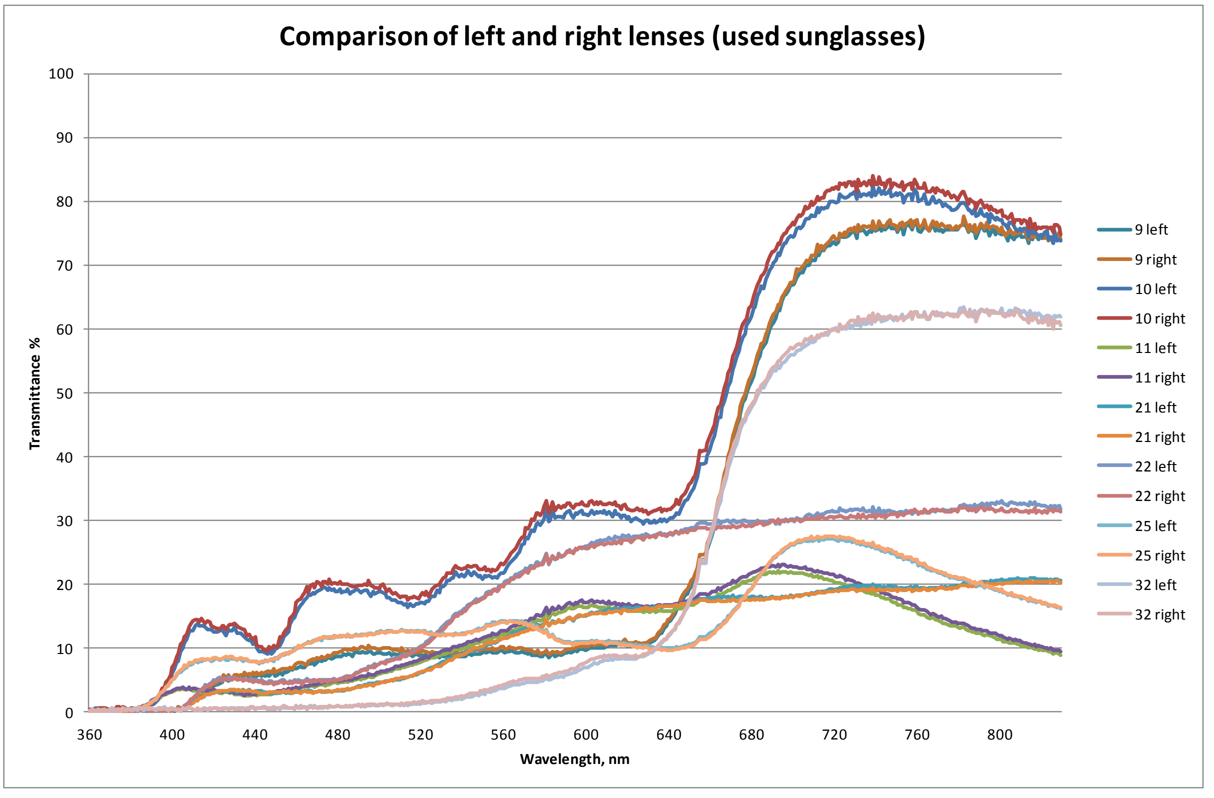

Figure 9-d Comparison of left and right lenses from a selection of used sunglasses.

Transmittance measurements were captured from one lens for most of the new sunglasses measured. Figure 9-e shows examples of new sunglass transmittance curves where both lenses were measured.

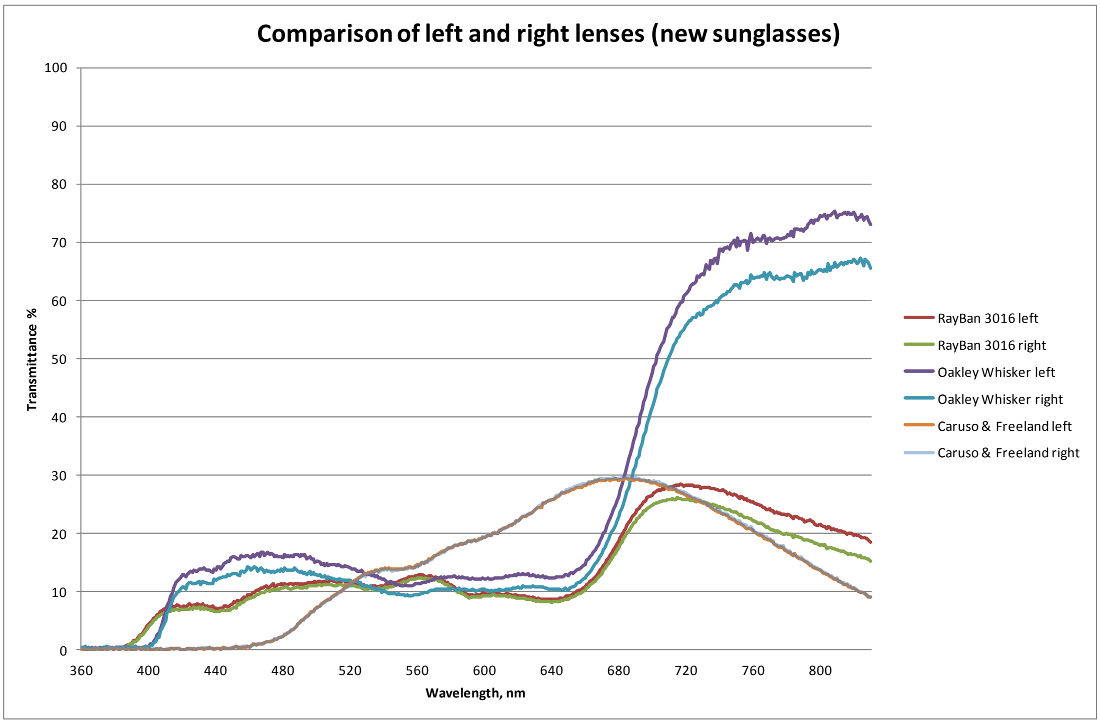

Figure 9-e Comparison of left and right lenses from a selection of new sunglasses.

9.4.2 Effect of polarised lenses

It was not known if the fibre optic cable or spectrometer would be sensitive to polarised lenses. One pair of new sunglasses measured (RayBan RB3025P) was known to have polarised lenses. Therefore, further measurements were taken with the sunglasses rotated as described in section 9.3.1. The transmittance curves were unaffected by the orientation of measurement (Figure 9-f). Results showed that the data was not affected by the presence of polarised radiation.

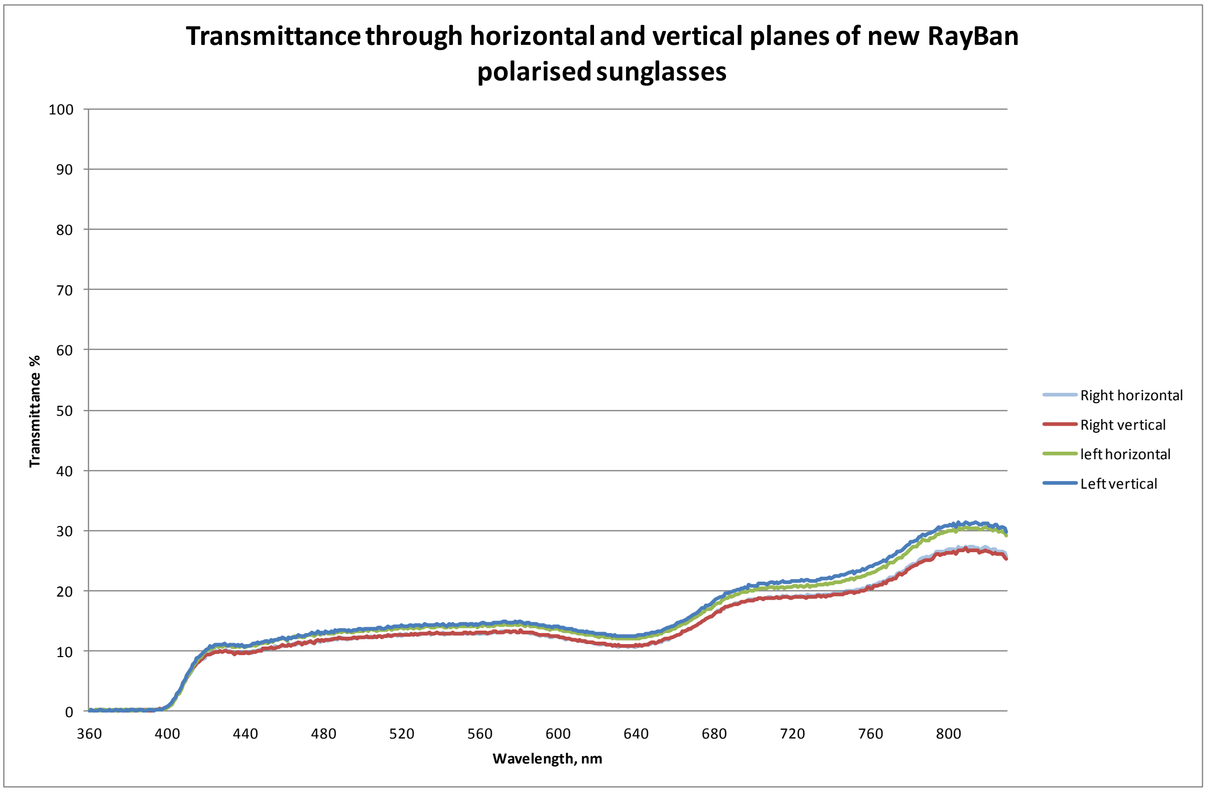

Figure 9-f Effect of rotation of polarised filters on spectral transmittance measurements.

9.4.3 Pilot sunglasses

A total of 34 pairs of pilot sunglasses were measured. Additionally measured were four pairs of new Bigatmo sunglasses (included in the new sunglass results in section 9.4.4) and a front visor from an Airbus A320 (compared to visor measured during ground transmittance measurements in section 8.3 and discussed in section 10.4). The visor tint was noted to be graduated and the sample presented had heavy fingerprint mark contamination. For measurement purposes, one half of the visor was thoroughly cleaned with the 'selvyt' cloth (a commonplace cloth designed to clean spectacle lenses; www.selvyt.com) and transmittance measurements were taken through top, middle and bottom sections of the visor from both clean and contaminated sides.

A summary of the pilot sunglasses measured is shown in Table 9-a. It can be seen that five pairs of sunglasses had no identifiable model number.

Make	Model	Number
RayBan	RB3404 3N	10
	RB3026 2N	
	RB3293 3N	
	RB4057 3N	
	RB8305 3N	
	RB4075 3N	
	RB3990 3N	
	RB3467 3P	
	Wayfarer 3N	
	No model no. (3N)	
Oakley	Whisker (2)	6
	Crosshair	
	Tightrope	
	Minute	
	Squarewire	
Serengeti	Pisa	6
	Velocity 6692 (4)	
	Brando prq	
Police	S8527N OK05	2
	No model no.	
Ted Baker	Porter cat 3	1
Prada	No model no.	1
M&S	No model no.	1
unknown	No model no.	1
prescription		6

Table 9-a Details of used pilot sunglasses presented for measurement.

The first two pairs of sunglasses measured had very low transmittance values (<0.2%) across the spectra which would be too low for a sunglass lens. It is not known the cause of this experimental error however it could have been due to a temporary fault within the lamp's optical shutter which caused it to not fully open during measurement. The data from these two sunglasses were excluded. Data from the six prescription pairs of sunglasses were excluded from analysis as the degree of beam divergence and dispersion through a prescription lens was not known; this factor would likely cause false low transmittance values.

Five of the Serengeti sunglasses were known to be photochromic and data from these has been analysed separately and are presented in section 9.4.6. Additionally, the Oakley Crosshair sunglasses measured had a graduated tint and a transmittance curve similar to a photochromic lens. Oakley product information revealed that this pair of sunglasses was not manufactured with a graduated tint. It was suspected that different lenses, probably photochromic, have been glazed into this particular frame at some point. It was decided to include this pair of sunglasses within the photochromic data.

The remaining sunglasses consisted of 15 pairs with uniform tints and 5 pairs with a graduated tint. Data presented are the result of the mean value from right and left lenses. Figure 9-g shows the transmittance of uniform tints at 315, 350, 365, 380, 400 and 440nm points (within UVA range and at the peak of the blue light hazard function). Examples of full spectra transmittance curves are shown in section 9.4.1.

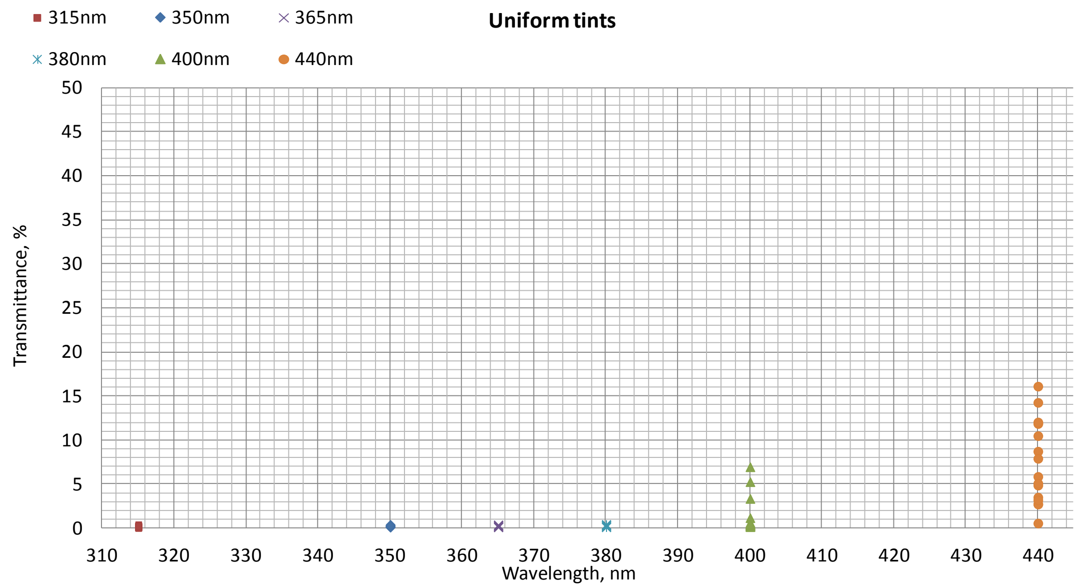

Figure 9-g Transmittance of uniform tints at 315, 350, 365, 380, 400 and 440nm points.

Figure 9-h, Figure 9-i and Figure 9-j show transmittance data from top, middle and bottom parts of graduated tinted lenses respectively.

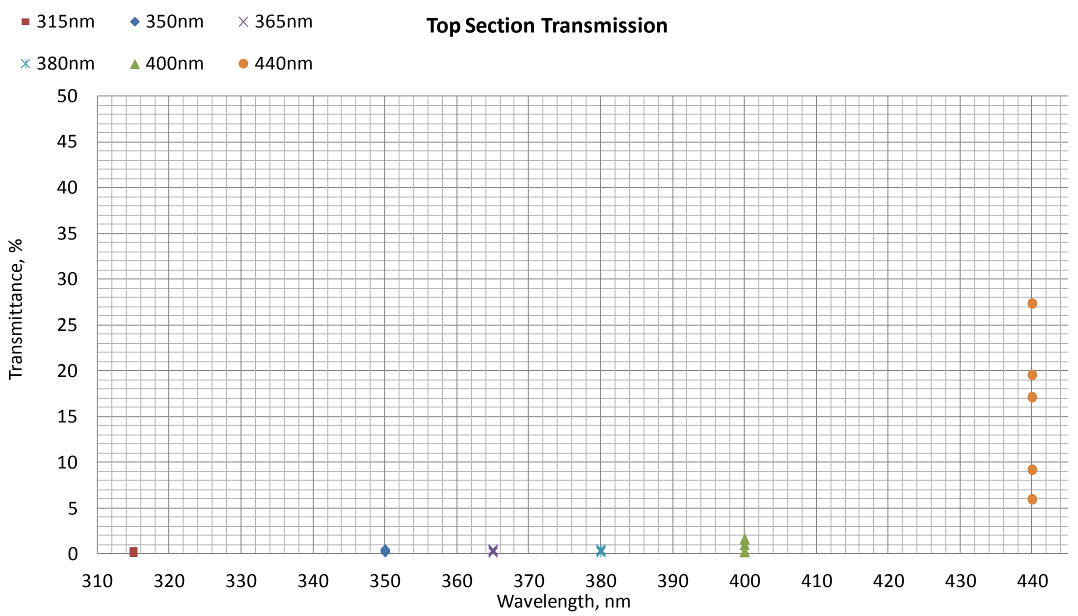

Figure 9-h Transmittance of the top section of graduated tints at 315, 350, 365, 380, 400 and 440nm points.

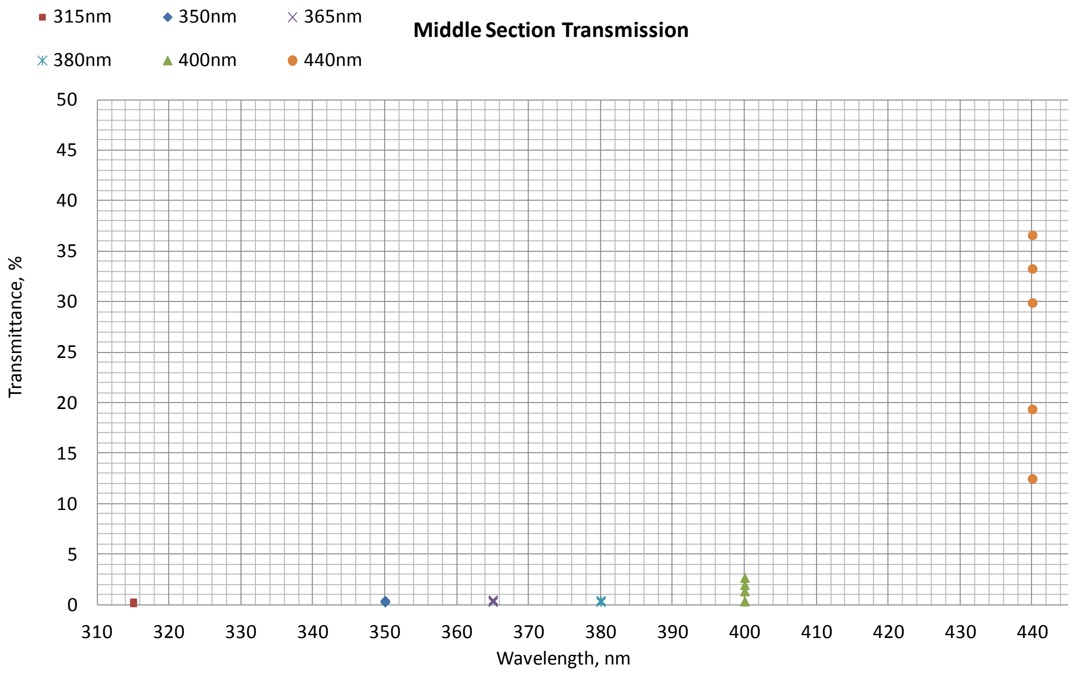

Figure 9-i Transmittance of the middle section of graduated tints at 315, 350, 365, 380, 400 and 440nm points.

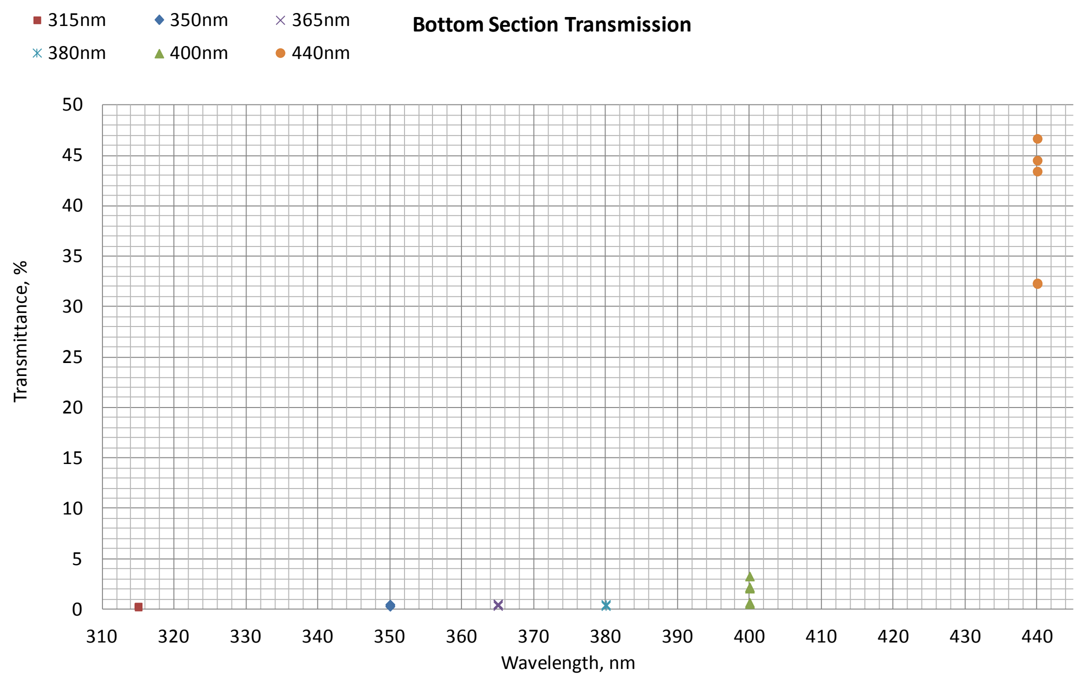

Figure 9-j Transmittance of the bottom section of graduated tints at 315, 350, 365, 380, 400 and 440nm points.

Figure 9-k to Figure 9-p show more detailed comparison of transmittance values of uniform tints and top and middle sections of graduated tints at 315, 350, 365, 380, 400 and 440nm. All sunglasses in this group were found to have transmittance values lower than 0.6% at all wavelength points up to 380nm. At 400nm, the highest transmittance for uniform tinted sunglasses was 7.0% (Ted Baker) followed by 5.3% (RayBan). All other uniform tinted pilot sunglasses measured had a transmittance below 1.2% at 400nm. At 400nm, all graduated tints (n=5) showed a transmittance values of less than 1.6% at the top of the lens. The highest transmittance measured at the centre of a graduated tint was 2.7%. The highest transmittance measured at the bottom of a graduated tinted lens was 3.3%. Note that Figure 9-o and Figure 9-p have a different y axis scale.

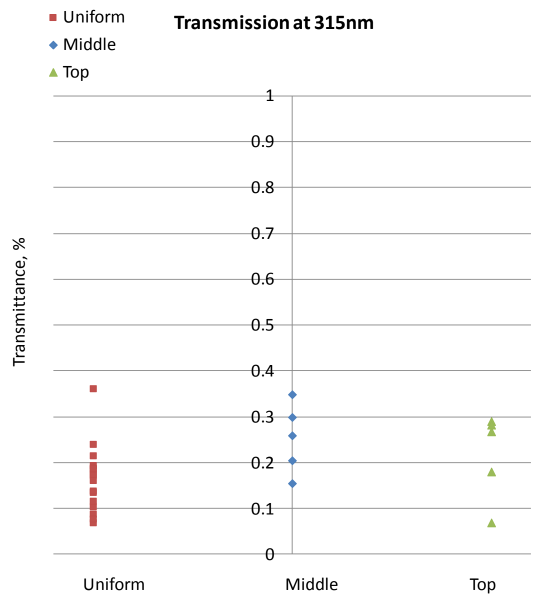

Figure 9-k Comparison of Transmittance of uniform and top and middle sections of graduated tints at 315nm.

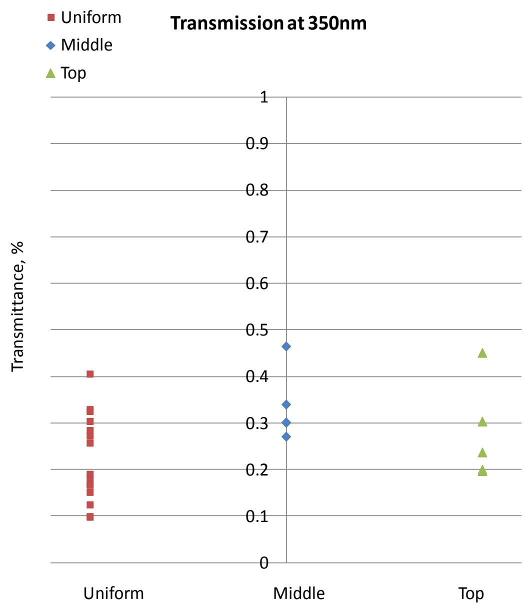

Figure 9-l Comparison of Transmittance of uniform and top and middle sections of graduated tints at 350nm.

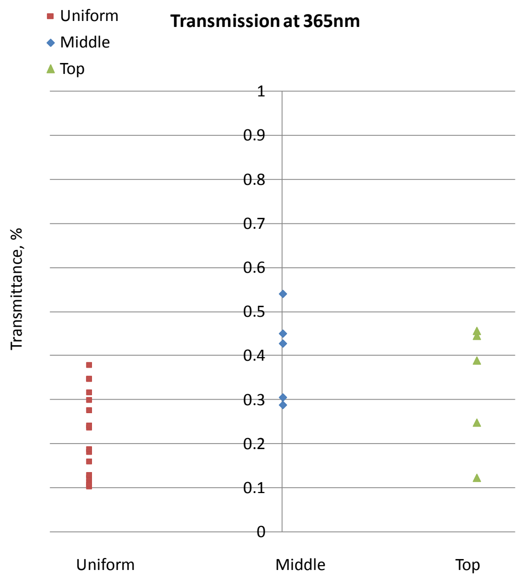

Figure 9-m Comparison of Transmittance of uniform and top and middle sections of graduated tints at 365nm.

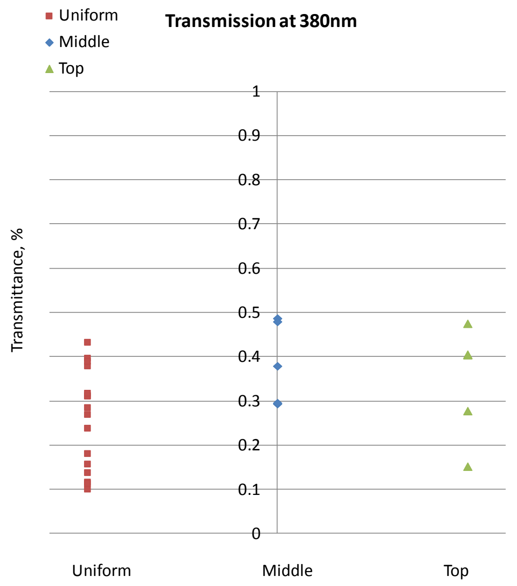

Figure 9-n Comparison of Transmittance of uniform and top and middle sections of graduated tints at 380nm.

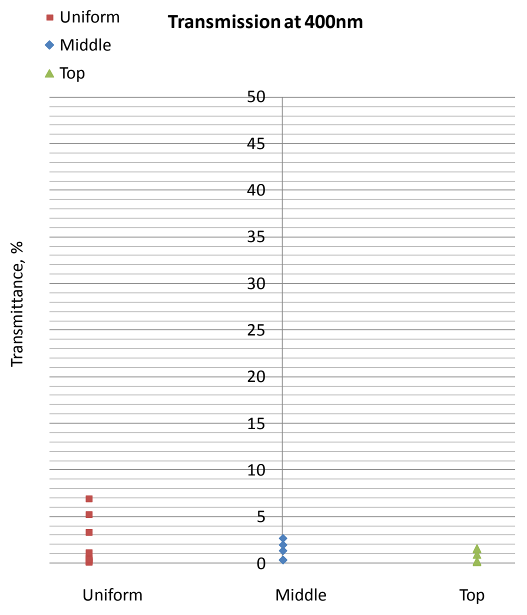

Figure 9-o Comparison of Transmittance of uniform and top and middle sections of graduated tints at 400nm.

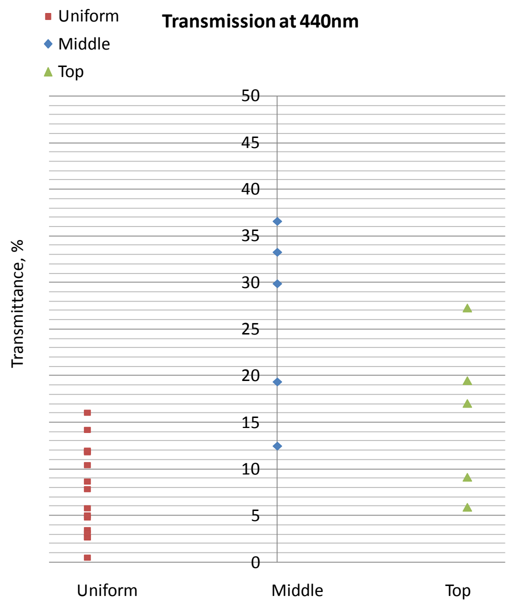

Figure 9-p Comparison of Transmittance of uniform and top and middle sections of graduated tints at 440nm.

A wider variation was seen in transmittance at 440nm with the highest of 16.1% (Police) and lowest of 0.6% (RayBan) for uniform tinted pilot sunglasses. For graduated tinted pilot sunglasses (n=5, all RayBan), transmittance varied between 6.0% to 27.3% at the top of the lens and increased to between 32.3% to 46.7% at the bottom of the lens.

The lenses on one pair of Oakley Whisker sunglasses were found to be particularly contaminated with smear and fingerprint marks. Transmittance measurements were taken before and after cleaning of the lens. The transmittance results are shown in Figure 9-q and showed no measurable difference in the UVA range.

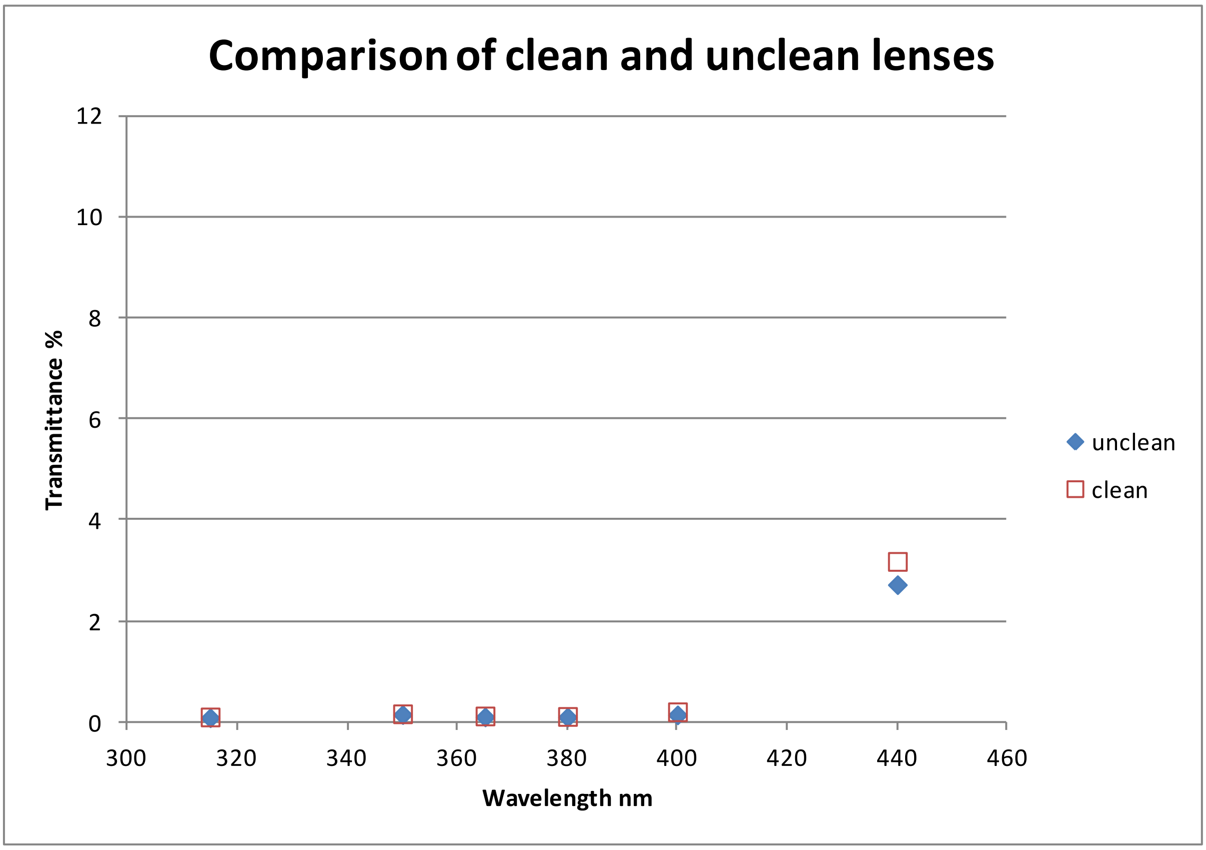

Figure 9-q Transmittance of a lens before and after cleaning.

All uniform and graduated sunglasses measured had an average UVA transmittance less than 1% for the wavelength range 315-400nm. Analysis of the maximum UVA transmittance (at 400nm) for uniform and graduated sunglasses is shown in Figure 9-r.

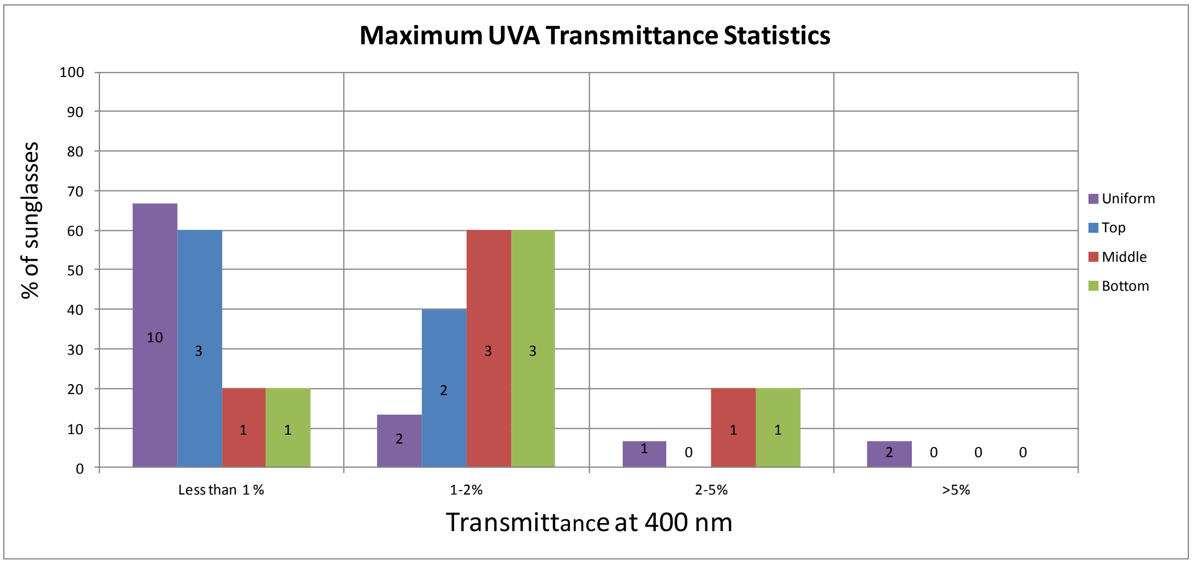

Figure 9-r Maximum UVA transmittance at 400nm.

The wavelength at which the threshold for transmittance of 1% and 2 % for uniform and graduated sunglasses was also assessed. The results are shown in Figure 9-s and Figure 9-t respectively. The wavelengths at which the two pairs of uniform sunglasses whose 1% transmittance occurred within the range of 370-390nm was 387 and 390nm.

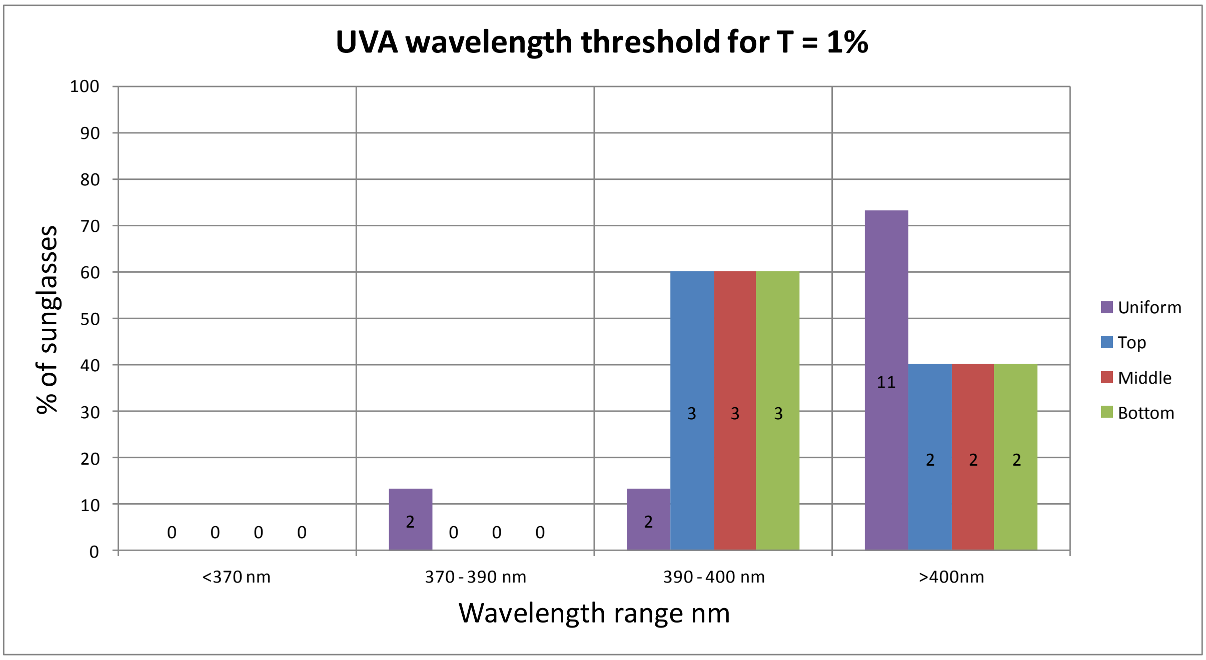

Figure 9-s Threshold at which 1% UVA is transmitted.

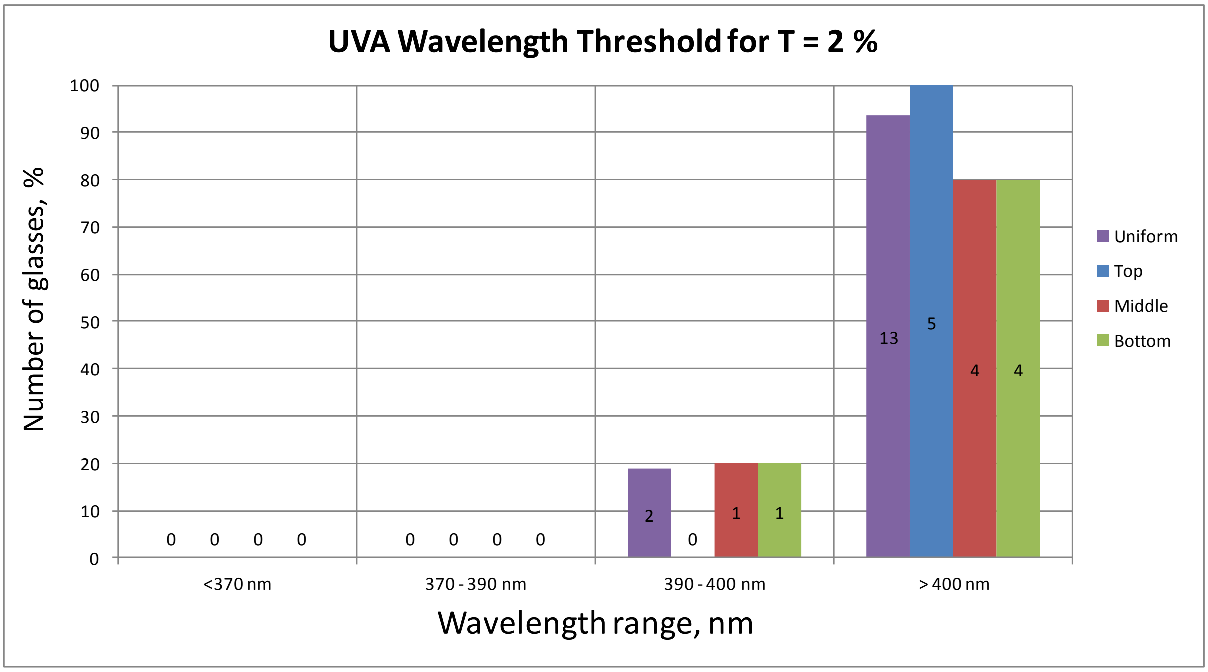

Figure 9-t Threshold at which 2% UVA is transmitted.

The transmittance curves of uniform tinted RayBan sunglasses measured compared to the top, middle and bottom of RayBan graduated sunglasses are shown in Figure 9-u to Figure 9-w respectively.

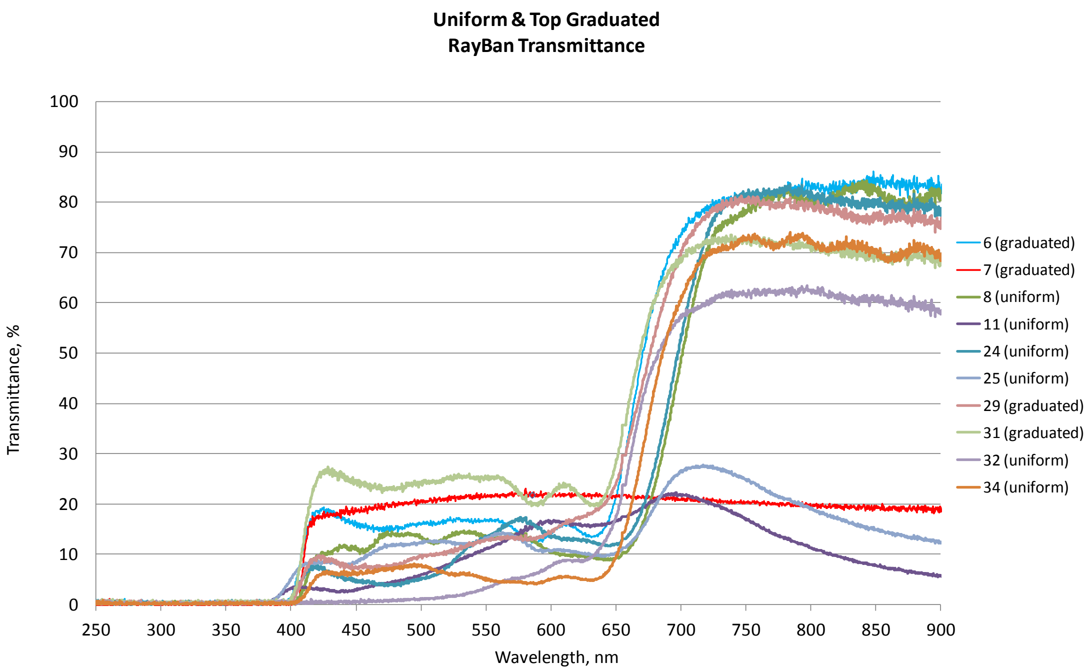

Figure 9-u Spectral transmittance curves for a series of uniform and top section of graduated tinted RayBan sunglasses.

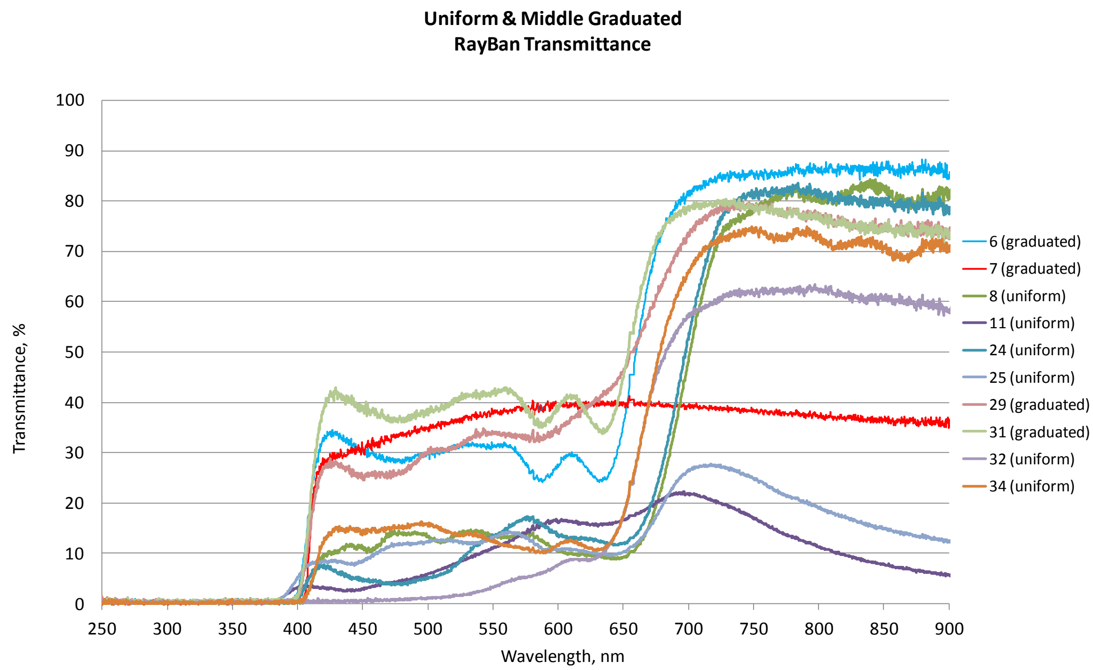

Figure 9-v Spectral transmittance curves for a series of uniform and middle section of graduated tinted RayBan sunglasses.

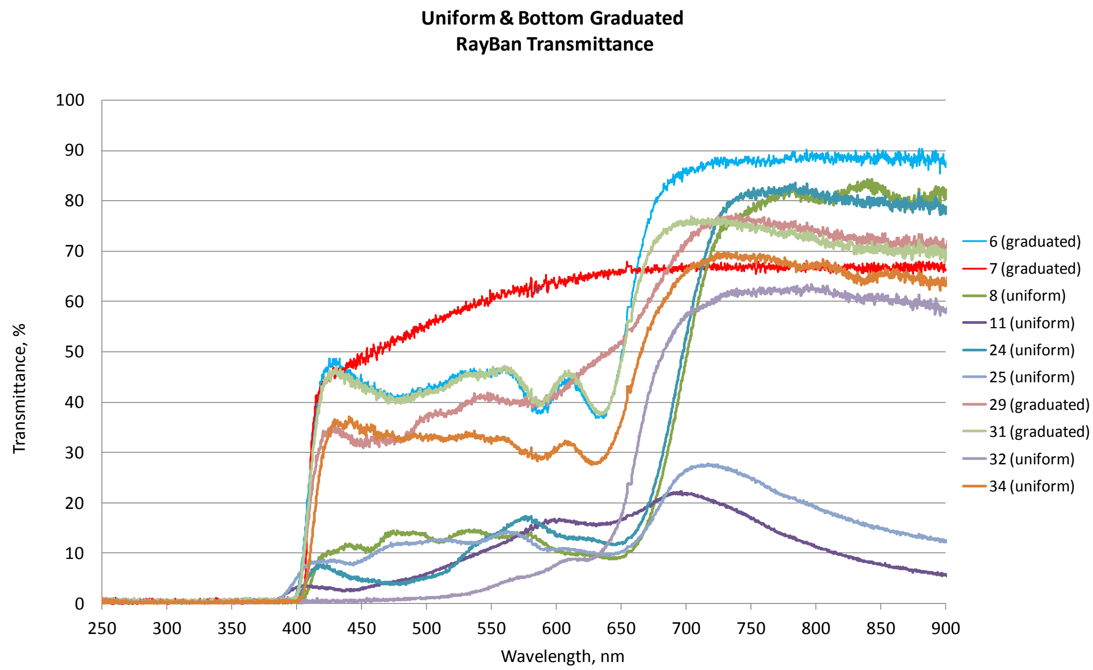

Figure 9-w Spectral transmittance curves for a series of uniform and bottom section of graduated tinted RayBan sunglasses.

9.4.4 New sunglasses

Sixteen pairs of sunglasses were assessed which, including the four pairs of Bigatmo sunglasses previously measured gives a total of 20 new sunglasses. A summary of the types measured are shown in Table 9-b.

Make	Model	Number
RayBan	RB3016	3
	RB 3025 graduated	
	RB4180	
Oakley	Whisker	5
	Jupiter	
	Pitbull	
	Fuel Cell	
	neutral density	
Police	S8743	3
	S8748	
	S8750	
Lacoste	1345	1
Prada	54is	3
	51os	
	57ls	
Caruso & Freeland	Cr188	1
Bigatmo	HCNB S14	4
	HCNB polarised	
	Grey mirror	
	Copper P20 photochromic	

Table 9-b Details of new sunglasses used for measurement.

The sunglasses consisted of 14 pairs with uniform tints, five pairs with a graduated tint and one photochromic. Where both lenses were assessed, data presented are the result of the mean value from right and left lenses. Photochromic lens data is presented separately. Figure 9-x shows the transmittance of uniform tints at 315, 350, 365, 380, 400 and 440nm points.

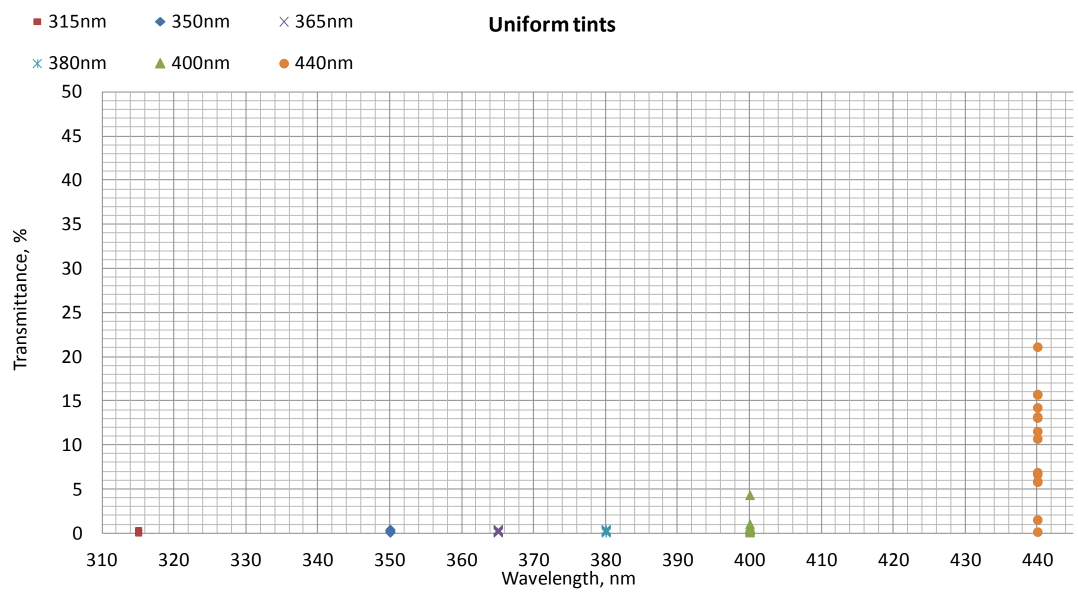

Figure 9-x Transmittance of uniform tints at 315, 350, 365, 380, 400 and 440nm points.

Figure 9-y, Figure 9-z and Figure 9-aa show transmittance data from top, middle and bottom parts of graduated tinted lenses respectively.

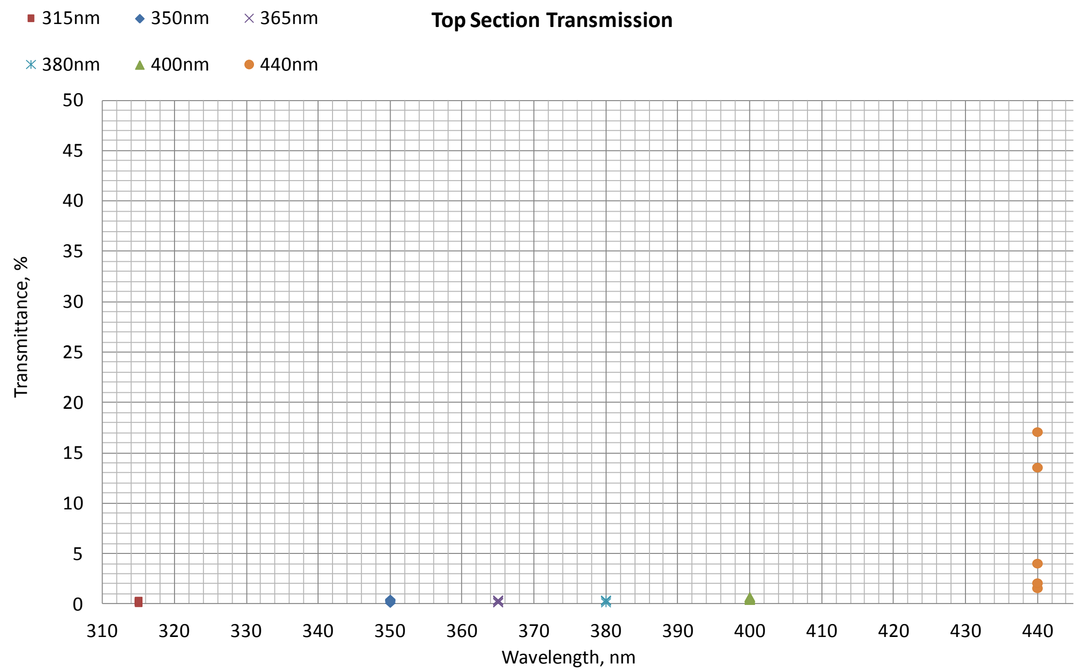

Figure 9-y Transmittance of the top section of graduated tints at 315, 350, 365, 380, 400 and 440nm points.

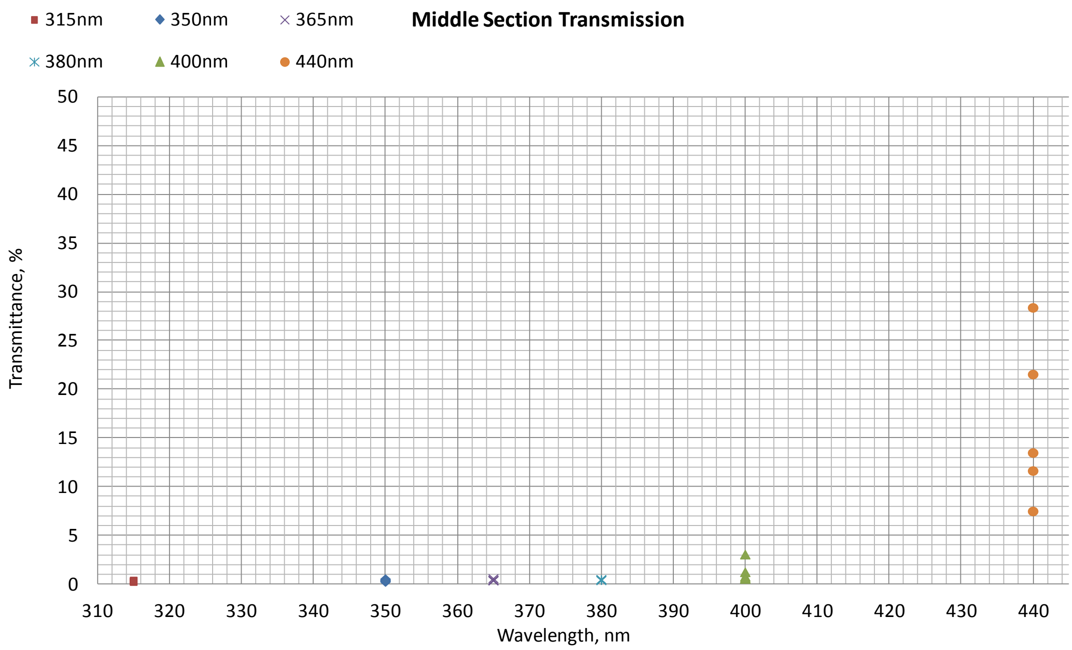

Figure 9-z Transmittance of the middle section of graduated tints at 315, 350, 365, 380, 400 and 440nm points.

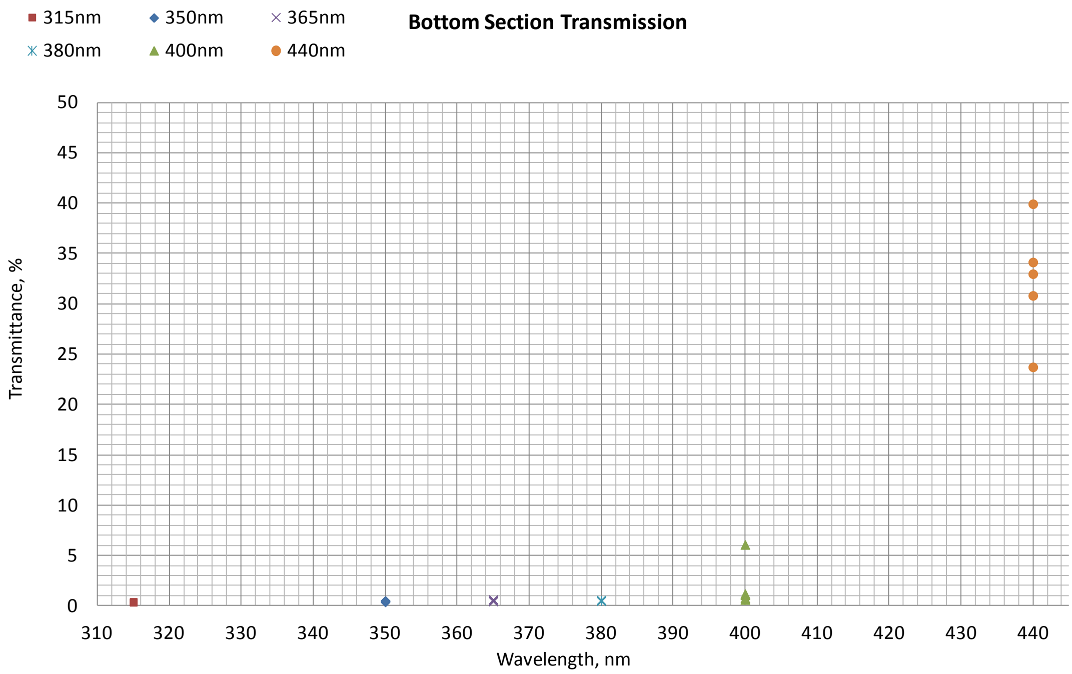

Figure 9-aa Transmittance of the bottom section of graduated tints at 315, 350, 365, 380, 400 and 440nm points.

Figure 9-bb to Figure 9-gg show more detailed comparison of transmittance values of uniform tints and top and middle sections of graduated tints at 315, 350, 365, 380, 400 and 440nm and also showed that no sunglass measured had a transmittance

above 0.6% up to and including 380nm. At 400nm, the highest transmittance for uniform tinted sunglasses was 4.4% (RayBan). All other new uniform tinted sunglasses measured were within 1.1%. All graduated tints (n=5) showed transmittance values within 1% at 400nm at the top of the lens. The highest transmittance measured at the centre of a graduated tint was 3.1%. The highest transmittance measured at the bottom of a graduated tinted lens was 6.1%. Note that figures Figure 9-ff and Figure 9-gg have a different y axis scale.

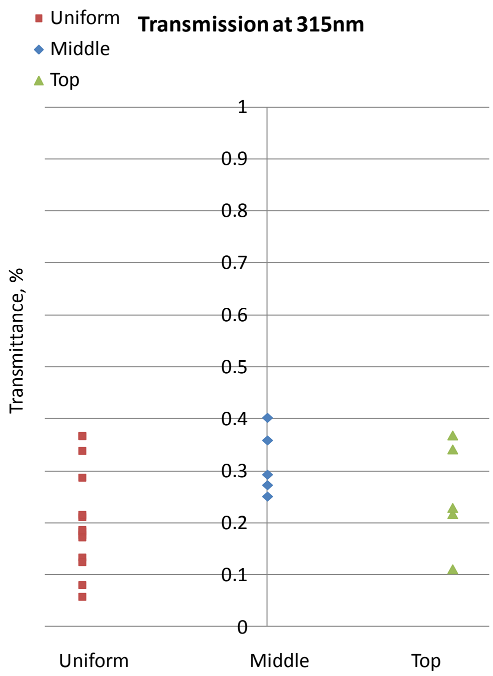

Figure 9-bb Comparison of Transmittance of uniform and top and middle sections of graduated tints at 315nm.

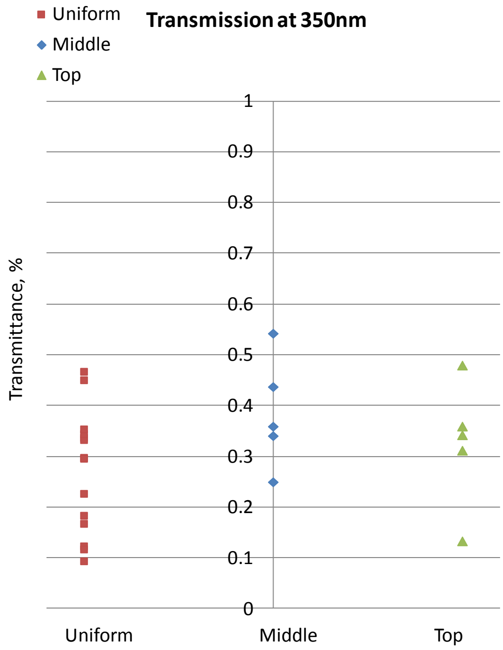

Figure 9-cc Comparison of Transmittance of uniform and top and middle sections of graduated tints at 350nm.

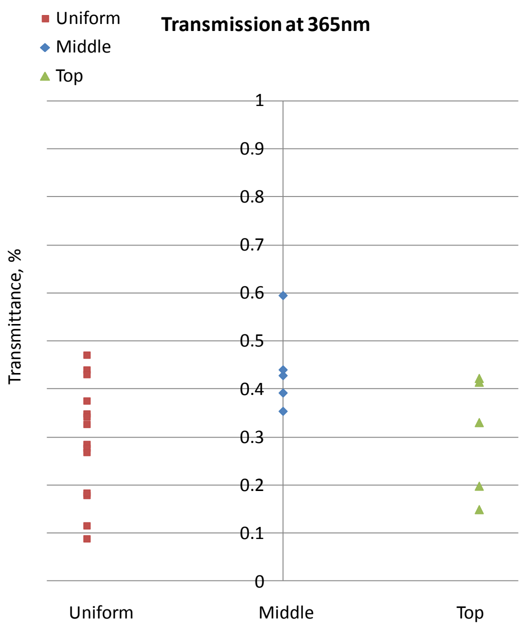

Figure 9-dd Comparison of Transmittance of uniform and top and middle sections of graduated tints at 365nm.

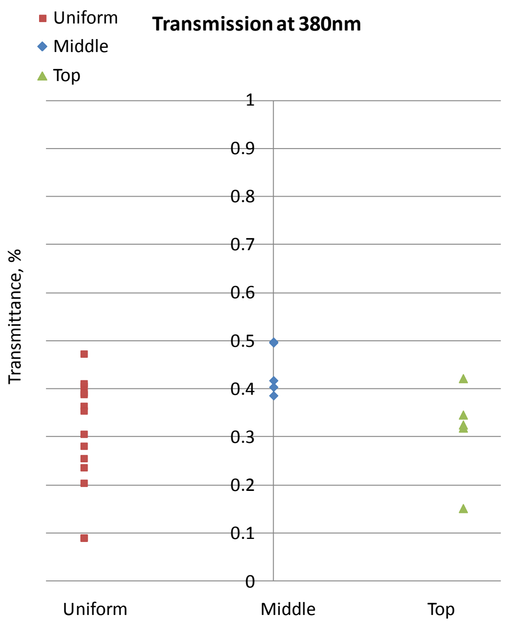

Figure 9-ee Comparison of Transmittance of uniform and top and middle sections of graduated tints at 380nm.

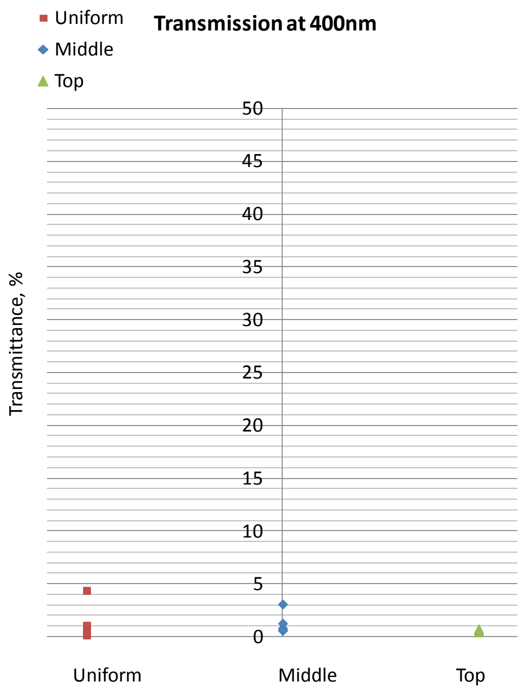

Figure 9-ff Comparison of Transmittance of uniform and top and middle sections of graduated tints at 400nm.

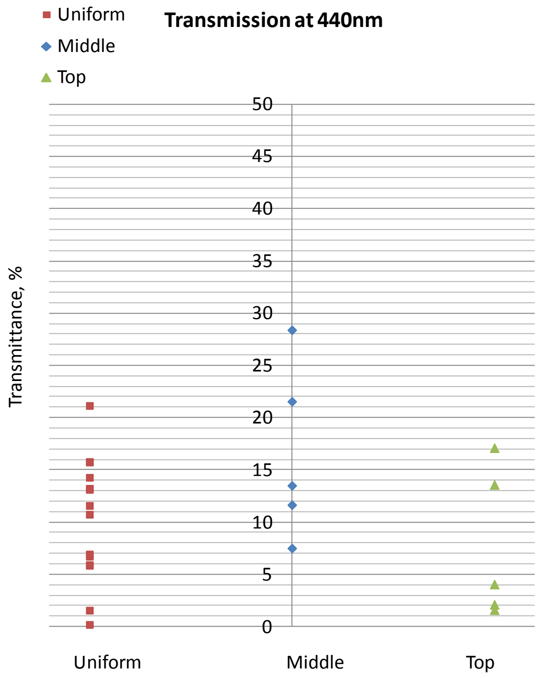

Figure 9-gg Comparison of Transmittance of uniform and top and middle sections of graduated tints at 440nm.

A wider variation was seen in transmittance at 440nm with the highest transmittance of 21.1% (LaCoste) and lowest of 0.2% (Caruso & Freeland) for uniform tinted sunglasses. For graduated tinted sunglasses, transmittance varied between 1.6% (Prada) to 17.1% (RayBan) at the top of the lens increasing to between 23.7% (Police) to 40.0% (RayBan) at the bottom of the lens.

All sunglasses measured had an average UVA transmittance less than 1% for the wavelength range 315-400nm. The maximum UVA transmittance (at 400nm) for uniform and graduated sunglasses is shown in Figure 9-hh.

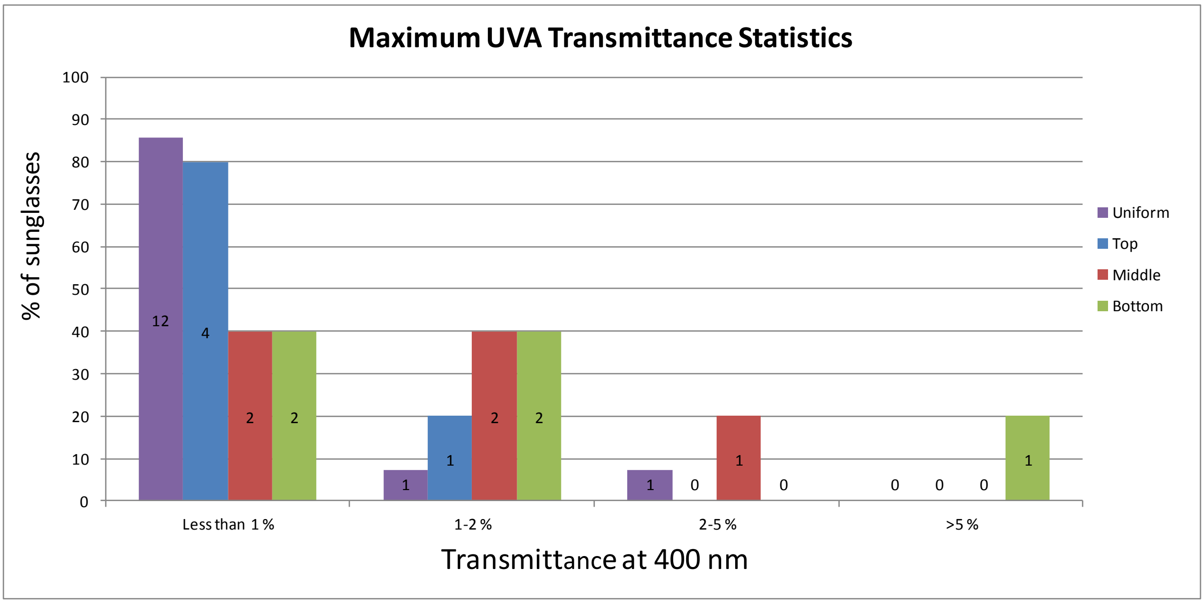

Figure 9-hh Maximum UVA transmittance at 400nm.

The wavelength at which the threshold for transmittance of 1% and 2 % for uniform and graduated sunglasses was assessed. The results are shown in Figure 9-ii and Figure 9-jj respectively. The wavelength at which the one pair of uniform sunglasses whose 1% transmittance occurred within the range of 370-390nm was 389.8nm.

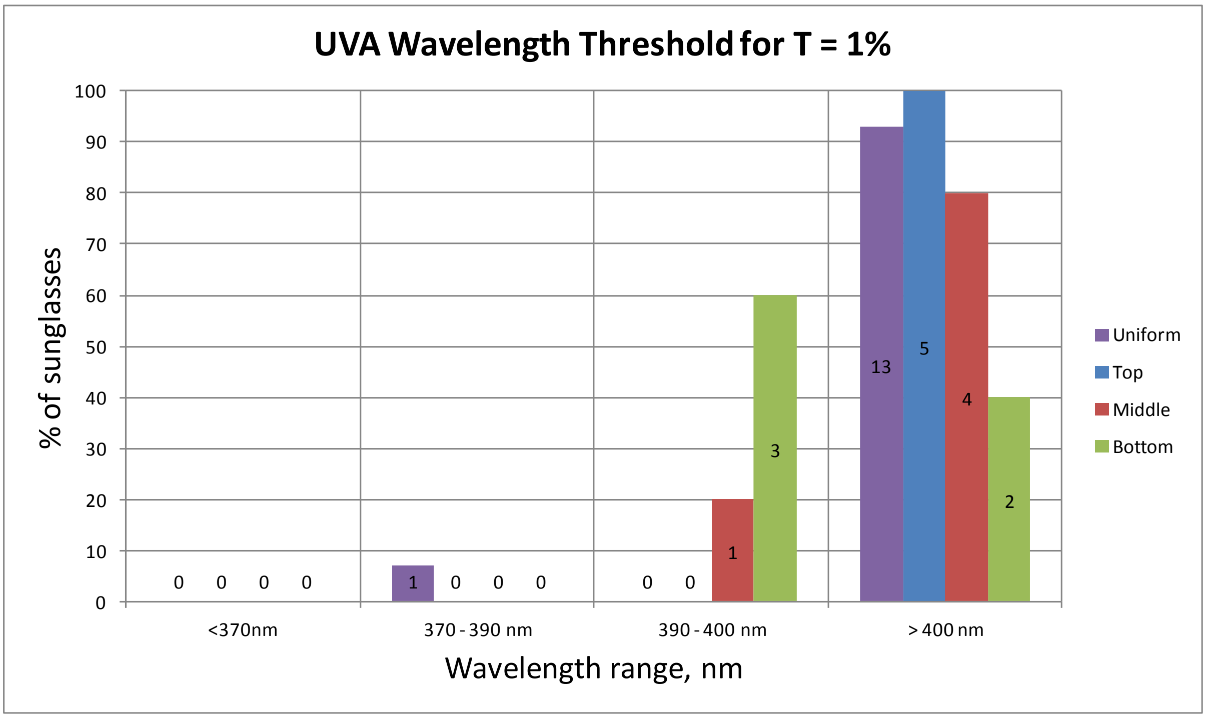

Figure 9-ii Threshold at which 1% UVA is transmitted.

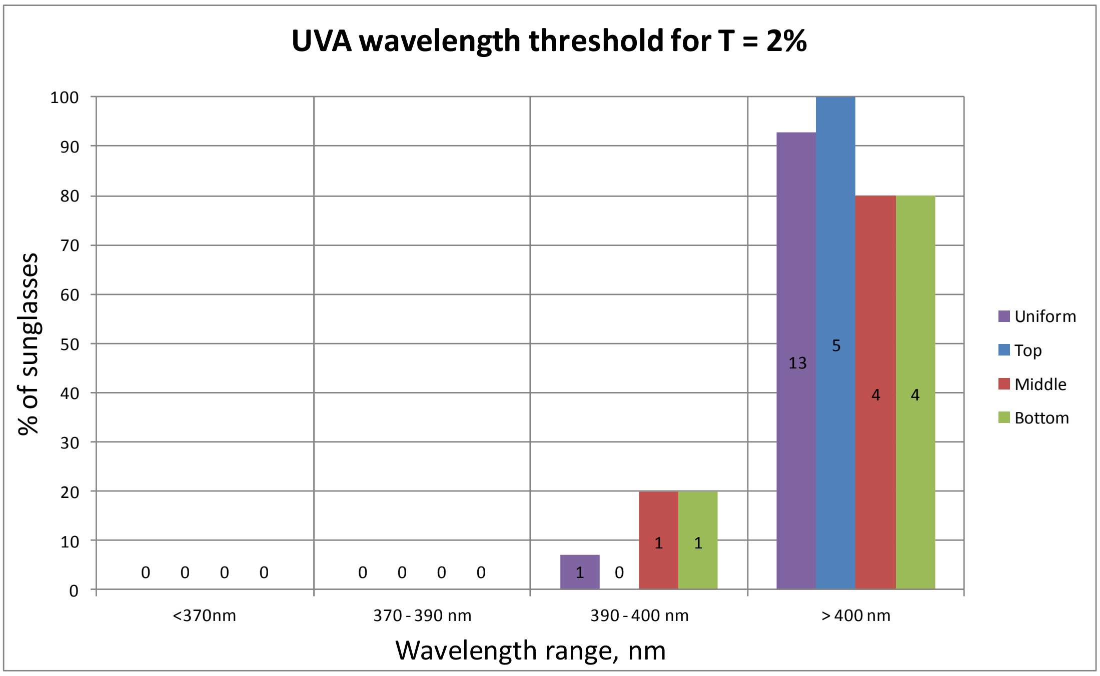

Figure 9-jj Threshold at which 2% UVA is transmitted.

9.4.5 Comparison of old and new sunglasses

One pair of new Oakley Whisker sunglasses was measured. Transmittance data were compared with the two used Oakley Whisker sunglasses. A summary of the transmittance at 315, 350, 365, 380, 400 and 440nm is shown in Figure 9-kk.

Figure 9-kk Comparison of transmittance points of used grey and brown tinted Oakley Whisker sunglasses with a new (grey) equivalent model.

There was insufficient data to statistically determine whether a difference in transmittance was present between new and used sunglasses however the data do not suggest that used sunglasses have noticeably higher transmittance than new sunglasses. No data was collected from pilots during this phase of data collection regarding the age of their sunglasses.

Two pairs of pilot sunglasses were noted to have scratched lenses. These were both RayBan sunglasses with graduated tints and they also were found to have the highest transmittance at 440nm.

9.4.6 Photochromic sunglasses

Data from the photochromic sunglasses were analysed separately and presented below. These included five pairs of used Serengeti sunglasses, sunglass 19 with suspected photochromic lenses in an Oakley frame and a new pair of Bigatmo Copper P20 photochromic sunglasses. All lenses were measured as presented and the state of the photochromic lens activation was not known. Serengeti lenses also had a graduated tint and the transmittance curves for upper and lower parts of the lenses are shown in Figure 9-ll and Figure 9-mm respectively.

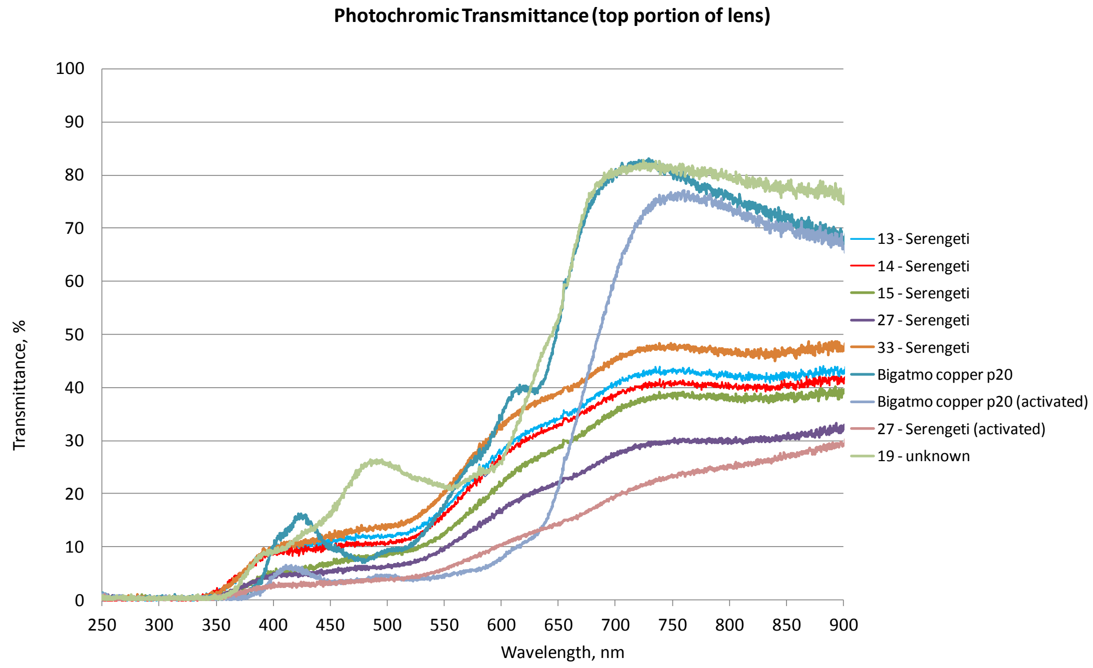

Figure 9-ll Spectral transmittance curves through the top part of photochromic lenses measured.

One pair of sunglasses (no. 27) was measured immediately following exposure to a UV pen light (type and power output unknown) for approximately 1 minute to the centre of the lens. This is shown in Figure 9-ll.

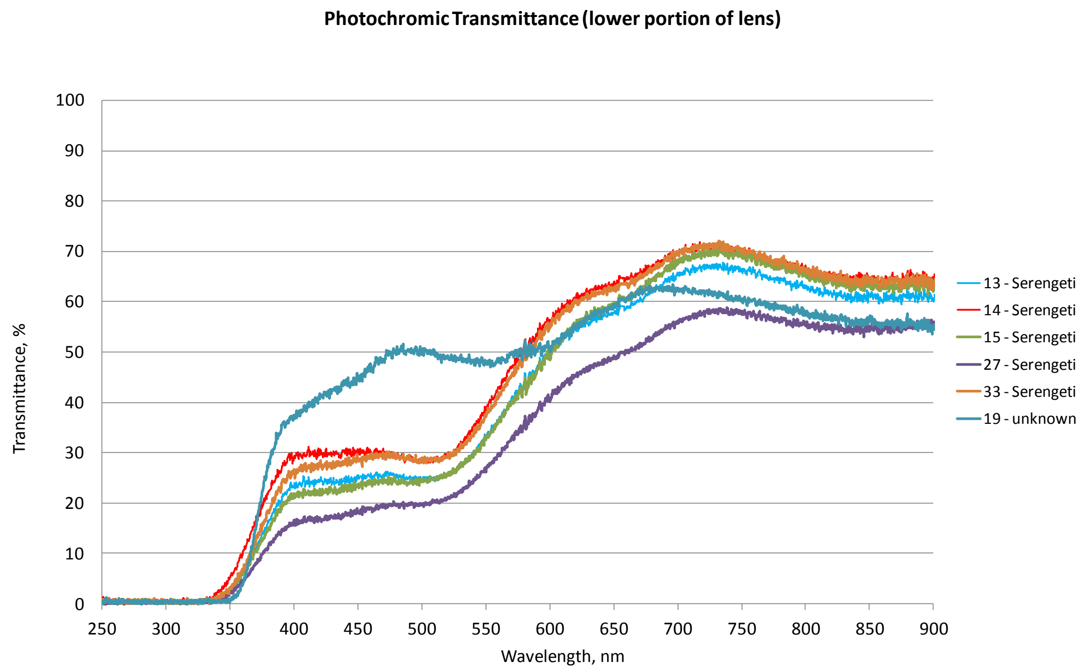

Figure 9-mm Spectral transmittance curves through the bottom part of photochromic lenses measured.

9.4.7 Solar UVA/luminous transmittance

Further analysis was conducted on three pairs of uniform tinted sunglasses (two new and one used). One of the new pairs of sunglasses had the highest transmittance at 400nm of all new uniform tinted sunglasses measured.

For each of three sunglasses, the luminous transmittance between 380-780nm was calculated using the V(λ) function and the energy distribution a D65 light source as described in ISO 12311 (2013). The solar UVA transmittance for the 315-380nm range was calculated using the weighting function as described in ISO 12311 (2013). The luminous transmittance of all three sunglasses fell within the 8-18% category 3 filters under ISO 12312 classified as general purpose sunglasses. The solar UVA transmittance / luminous transmittance were 0.01 and 0.06 for the two new sunglasses and 0.02 for the used sunglasses.

9.5 Discussion

Of the used pilot sunglasses presented for measurement, the most prevalent was RayBan (n=10, 29%) followed by Oakley (n=6, 18%) and Serengeti (n=6, 18%). These were also the most prevalent three makes of sunglasses found in section 4.9

where, of the sunglass users, RayBan were worn by 32.1% of respondents, Oakley were worn by 19.1% and Serengeti sunglasses were worn by 8.6% of respondents. Prescription sunglasses were used by 16.8% of sunglass users in the questionnaire and found in 18% of the used sunglass sample presented. It would be reasonable to conclude that the sample of used sunglasses presented offered a good representation of the general population of sunglass wearing pilots.

All sunglasses presented were measured, however as discussed in section 9.4.3, all prescription sunglasses were excluded from analysis. Additionally, a number of photochromic lenses were presented. The activation state of these lenses was unknown and it was not possible to measure in their fully activated state. Figure 9-ll shows the general effect of a degree of activation however full analysis of their effectiveness in the cockpit environment cannot be certain. A degree of activation should take place in the cockpit, particularly behind a poor UVA attenuating windshield. Based on this, there is no reason to believe that photochromic lenses would not meet the suggested minimum criteria for aviation use as discussed in section 10.9.

It is recognised that used sunglasses filters were not assessed for polarisation. This would have been straightforward to conduct by using a known polarising filter and checking the sunglass lens with cross polarisation. With the exception of Serengeti sunglasses, one pair of used sunglasses was known to be polarised from its model number. It is anticipated that the prevalence of polarised sunglass filters in the pilot population would be low as not only do polarised lenses sold represent a minority of the market share (personal communication, H Obstfeld 04/08/14) but additionally all published pilot sunglass information discourages their use for aviation.

All uniform and graduated tinted sunglasses measured showed good UVA attenuation to 380nm. This is unsurprising as ISO 12312-1, 2013 requires minimum lens transmittance requirements up to 380nm. Between 380-400nm there is a wider transmission range seen in both new and used sunglasses although 84% (42/50) had a measured transmittance of less than 2% at 400nm. The sunglasses with the highest transmittance at 400nm were a pair of used sunglasses (no. 10) whose transmittance curve can be seen in Figure 9-d. Interestingly, these sunglasses had a dip in the transmittance curve at 440nm offering lower transmittance at the peak of the blue light hazard and a level (mean 10.5%) well within the range of other sunglasses.

One pair of sunglasses (Caruso & Freeland) had the lowest transmittance at 440nm of 0.2%. These sunglasses are specifically marketed for pilots and are advertised for their blue light blocking properties (Caruso & Freeland, no date).

There was no apparent difference in UVA and blue light attenuation between used and new sunglasses measured. This can be observed not only in the comparison of a used and new (assuming a grey tint) Oakley model (Figure 9-kk), but also the overall transmittance results within new and used sunglass groups. It is interesting to note that the sunglasses with the highest transmittance at 440nm were used sunglasses and were the only sunglasses to be recorded as having scratched or marked lenses. This finding is perhaps unsurprising as if the tint were applied to the lens surface during manufacture, subsequent surface damage could increase lens transmittance.

Similarly, a slight decrease in transmittance at 440nm was observed in a pair of used sunglasses with smeared or fingerprint marked lenses compared to the same lenses after cleaning. The obvious contamination may have reduced transmittance. Additionally, greater beam diffraction may have taken place causing a lower signal to be detected by the spectrometer's collimating lens.

It is reported (Dain et al, 2009) that many sunglass materials have a steady transmittance of 92% above 700nm. The remaining 8% is lost due to refection from each surface of the lens. Consideration was given to adjusting sunglass spectral transmittance data such that appropriate sunglass data would meet this 92% transmittance criteria. It is recognised that the column of radiation emitted from the first collimating lens may be affected by factors other than being absorbed by or reflected from the lens material. Beam displacement may occur where prismatic effects from the lenses are present. Additionally, where the filter is not positioned at an angle normal to the beam, a longer beam path through the lens may result. These factors may result in falsely low transmittance.

Data adjustment cannot be applied to other types of sunglasses including polarised and photochromic lenses (personal communication S. Dain 29/04/14). As measurement from pilot sunglasses involved data collection from all sunglasses presented, it was decided not to adjust data for only some types. It is however recognised that these transmittance values may be lower than if measured in a more controlled laboratory based environment.

Recommended minimum sunglass criteria for professional pilots are discussed in chapter 10. All sunglasses are comfortably able to attenuate UVA to a level within ICNIRP guidelines. Measurement uncertainties induced in transmittance data would not affect this conclusion. Suggestions for blue light hazard attenuation are also discussed (section 10.9) and the suggested level of attenuation is comfortably met by all sunglasses. It is recognised that it is possible that some of the poorer performing blue blocking sunglasses may fall outside this recommendation their data were adjusted to 92% transmittance beyond 700nm. However, this suggested level of blue light hazard attenuation is not due to acute retinal health concerns but a suggested level of protection based on typical irradiances at altitude and a lifetime of occupational blue light hazard exposure.

9.6 Results with reference to ISO

The purpose of the sunglass transmittance measurements was to assess the effectiveness of the typical sunglasses used by pilots at controlling exposure to short wavelength radiation in the cockpit environment using the new knowledge of irradiance levels received during flight.

This research did not aim to determine whether sunglasses met international minimum standards. ISO 12311 and 12312-1, 2013 transmittance requirements are based on sample tint measurement using a CIE Standard Illuminant D65 (ISO 11664-2). However, this is important where a single value is obtained using a broad-band meter between 380-780nm. Where spectral transmittance is measured, as in this research, the transmission data at each wavelength point is a relative value between source with and without the sunglass filter in place. Therefore, provided the source has sufficient output within the spectral range of interest, the calculations with reference to ISO should be unaffected by the use of a different light source.

For interest purposes, the formulae set out in ISO were used to calculate solar UVA transmittance between 315-380nm. The UVA transmittance / luminous transmittance values were low and within the limits for filter category 3 as set out in ISO.

There would seem no indication that other sunglasses used in this research would not meet UV transmittance requirements if tested. The percentage of filters tested that fail ISO UV specifications is likely to be minimal (Dain et al, 2010; personal communication H. Obstfeld 04/08/14).

9.7 Summary

The selection of pilot's used sunglasses that were measured offered a good representation of the types of sunglasses worn by pilots as discovered in chapter 4. All uniform and graduated tinted sunglasses measured showed good UVA attenuation up to 400nm. There was no reason to believe a significant difference is present between new and used sunglasses although those used sunglasses with noticeably scratched lenses showed the highest transmittance at 440nm. Marked lenses showed a marginal decrease in transmittance outside of the UV range. Only limited analysis has been carried out on photochromic sunglasses presented for measurement.

The results demonstrate that all sunglasses filters measured would offer sufficient UVA attenuation to reduce ocular exposure to within ICNIRP guideline limits. Based on the recommendation made in chapter 10, all sunglasses measured should also offer sufficient protection from the blue light hazard at altitude to result in an ocular exposure that is no greater than the mean exposure of the unprotected eye at ground level.

10. Chapter 10 Discussion and conclusions

CHAPTER OVERVIEW

This chapter aims to incorporate the findings from all three phases of the research. As discussed in chapter 3, this will include an assessment of the conditions under which the greatest risk of ocular exposure is present to the professional pilot. Evidence-based recommendations for pilot sunglass selection and recommendations to spectacle wearing pilots will be addressed together with identified areas for further future research. A number of other recommendations based on the results of this research are made to pilots, the CAA, eye care practitioners, and industry.

10.1 The flight deck environment

The visual task and pilot workload was observed to vary throughout flight. During the takeoff, climb and approach phases of flight, the aircraft is flown with primary use of the instruments. Therefore, a higher near vision workload would be present undertaking tasks such as frequent heading and altitude changes, changes of radio frequencies when communicating with air traffic control, changes of heading, airspeed or altitude when directed by air traffic and pilot referencing to charts and check lists.

During the cruise phase of flight, the overall workload is generally less but does include flight planning which is a near vision orientated task and includes monitoring and calculating fuel consumption, planning approach procedures, checking of alternate destination aerodrome and determining destination aerodrome information and local weather information. However, more time is generally available to undertake these tasks and there is likely to be a shift of attention from a generally eyes down position to a combination of eyes down and eyes ahead.

Although not present on the aircraft types flown for this study, new aircraft types such as the Boeing 787 have head up displays fitted. These allow flight information to be projected in front of the pilot as they adopt an eyes ahead position. Although no Boeing 787 was available for ground measurement, windshield transmittance measurements were captured from an Embraer 195 (Figure 10-a) which does have a head up display fitted.

Figure 10-a Embraer 195 with Head Up Display (HUD).

This windshield was considered a poor UVA attenuator (section 8.3). As the greater proportion of pilot's attention flying this aircraft is likely to be in the eyes ahead position where exposure is greater, ocular UVA may exceed recommended guideline limits after a shorter period of flight than in an aircraft with traditional flight instrument displays. The data show the head up display did not block UVA radiation and that new aircraft are more likely to have poor attenuating windshields. Further data on the windshield transmission properties of aircraft with head up displays is recommended however, this new finding reveals that pilots should be warned of the potential increased risk of ocular exposure to UVA and the blue light hazard unless sun protection such as a head up display visor or sunglasses are used.

10.2 Exposure at altitude

The cruise phase of flight coincides with the time where pilots are most likely to use sunglasses as discovered in section 4.9. This is perhaps unsurprising as firstly, the near vision task is less and pilots often report difficulty in quickly interpreting instruments through their sunglasses and secondly during the near vision intensive tasks, there is not the time available to put on sunglasses. Indeed, the observational data of pilots use of sunglasses shows that they were either put on before taxy or at the top of the climb and the start of cruise flight (section 6.2.20).

The data show that pilots have to potentially manage high irradiance levels in flight for example, during flight 4 Tobago (section 6.2.3.4) where illuminance levels reached nearly 120,000 lux at the windshield. High illumination in the cockpit should not be considered to be solely an issue for the airline pilot as it was also discovered during some helicopter flights where significant levels of irradiance were measured at relatively low altitude (section 6.2.18).

The results of section 4.9.4 also show that sunglass use is strongly driven by perceived overall illuminance levels. It was found that 69.6% of pilots wear sunglasses part of the time during flight (between 0-90%) however, it is not known to what extent sunglasses use may be initiated during the high workload periods during climb and descent. As the data demonstrate that light levels are generally higher at altitude than at ground level, sunglasses are likely to be initiated in the earlier stages of flight and removed in the latter stages of flight. It could be argued that removing sunglasses is a quicker process and less likely to disrupt pilot workload than the putting on of sunglasses particularly in the presence of a headset. The observational data (section 6.2.20) suggest that the pilot may postpone initiating sunglass use until there is felt to be sufficient time, with the knowledge that the climb phase of flight is relatively short.

It is reassuring that sunglasses are more likely to be worn during cruise as this is a time where irradiance levels are found to be higher (section 6.2.2). It was also found that all sunglasses measured are effective in reducing the potential UVA exposure to within recommended guideline limits. However, it was found that large increases in irradiance can also occur during takeoff, climb, descent and approach phases of flight. Although the total time of these phases of flight is less than the cruise phase (unless the flight is of a particularly short duration), a significant proportion of the ocular irradiance dose may be received during these times, particularly as the pilot is less likely to be using sunglasses. Indeed, data from flight 5 demonstrated that ocular exposure to UVA would exceed recommended limits within one hour of take-off unless solar eye protection was used. Ocular exposure was higher in the presence of a cloud top layer just below the aircraft, as is likely to occur during descent, and in the situation of a low relative solar elevation angle during climb. This can be seen in the results of flight 5 (section 6.2.3.5) and flight 6 (section 6.2.3.6)

10.3 Windshield transmittance

No measurable UVB was present during any flight which concurs with previous studies (Diffey and Roscoe, 1990; Kohn and Harper, no date). However, this study has shown that the transmission properties of the windshield are the most important factor in determining the levels of UVA present in the cockpit during flight. On board an aircraft with a good UVA attenuating windshield, data show that the unprotected eye is unlikely to receive a UVA dose outside recommended limits even if of long duration and during bright sunlight conditions. This may provide reassurance to the 24.6% of pilots who never or rarely (<10% of flight) use sunglasses (section 4.9.4).

Although Nakagawara et al (2007) report UVA transmission through some commercial aircraft windshields, the data presented in this research project has shown that most aircraft measured and importantly newer aircraft are likely to have poorer UVA attenuating windshields (section 8.4.1). Pilots independently report an assumption that windshields provide adequate protection from UV. The logic of this assumption includes knowledge that there is no skin tanning noted during flight and that the thickness of windshield is a measure of the degree of protection (section 4.9.9). Therefore, information should be readily available to professional pilots to state that some UV radiation may pass through the thick front aircraft windshields. Although this would be the less energetic, 'near visible' UVA part of the electromagnetic spectrum which doesn't cause skin tanning, external irradiance levels outside the aircraft at altitude are sufficiently high that a significant UVA dose may be received inside the cockpit. Sufficient UVA protection from a windshield should not be assumed.

The data presented show that the majority of commercial jet aircraft measured have windshields with poor UVA attenuation and that generally it is the older aircraft which have good UVA attenuating windshields. This, together with the limited data presented regarding replacement windshields (see section 8.6) indicate that newer cockpit windshields fitted on commercial passenger aeroplanes are likely to have poor UVA attenuation properties. This is a surprising finding and any explanation for this finding is limited as, despite efforts to contact both aircraft and windshield manufacturers, no information has been received at the time of writing. It is possible that there may be a higher financial implication of manufacturing a windshield with good UVA attenuating properties. Additionally, a windshield with good UVA attenuating properties will absorb more energetic radiation than its poor UVA attenuating equivalent. It is possible that this may cause a faster degradation of the windshield.

However, based on the data presented, it would be reasonable to conclude that the prevalence of good UVA attenuating windshields on commercial passenger aeroplanes will decrease over time as older fleets of aircraft (such as the Boeing 747) are replaced with new aircraft types (such as the Boeing 787).

Data show that the front visors absorb a large proportion of radiation including UV, although measurable levels of UVA are transmitted. Additionally, the visors cover only a proportion of the total windshield area and high levels of diffuse radiation are still present in the cockpit. Fitting all aircraft with good UVA attenuating windshields would ensure that all pilots are protected from UV radiation regardless of whether sunglasses are used.

There is limited data regarding helicopter windshields, however it is clear that there are aircraft with both good and poor UVA attenuating windshields. As with the professional fixed wing pilot, the helicopter pilot has no way of visually assessing the UVA attenuating properties of the windshield of the particular helicopter flown. The safest course of action would be to assume poor UVA attenuation through the windshield.

10.4 Aircraft visors and blinds

As described in section 10.3, front visors block a relatively small portion of the total front windshield area. Of the aircraft flown in this study, the Airbus A330 (flight 4) appeared to offer the largest screen coverage by being a retractable hard material which could be pulled down when required in a similar fashion as a traditional roller blind. All other jet aircraft were observed to have smaller visors which could be angled and were either attached to a rail or pivoted from a single point. Transmittance data were captured from an Airbus A320 visor in two phases of this research; during ground measurements (section 8.3) and during sunglass transmittance measurements (section 9.4.3) and are shown in Figure 10-b. Issues with potential variations in the (solar) source during ground measurements are discussed in section 8.5.

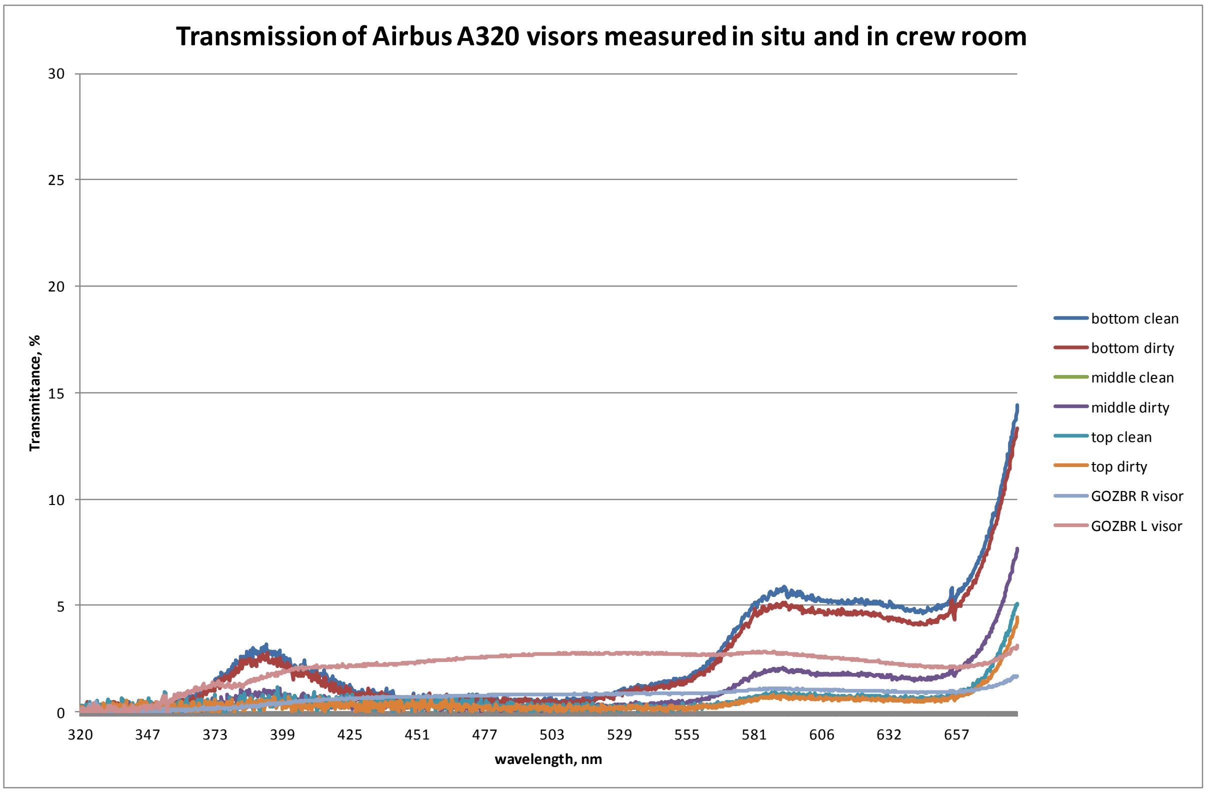

Figure 10-b Comparison of visor ground transmittance data against a solar source compared to the more controlled environment with the use of a deuterium tungsten halogen source. Note that the transmittance scale has been adjusted from 100%.

Transmittance curves through finger marked and cleaned areas of the visor were similar. Unsurprisingly, unclean areas had a marginally lower transmittance. This finding concurs with measurements through marked and cleaned sunglass lenses (p.240). The small variation around 657nm represents the effect of the emission line from the deuterium component of the lamp as discussed in section 9.3.1. At the time of ground measurements, it was not known that the Airbus visors had a slight graduated tint however it can be seen that all sections have minimal transmittance between around 450 to 550nm. Ground measurements showed the right visor to have similar transmittance in this area with the left approximately 2% higher. A small increase in UVA transmittance is seen particularly through the bottom section of the visor. This is unlikely to represent an experimental error but the effect of the normal transmission properties of the visor material together with the attenuation properties of the tint applied. It also confirms the findings in section 8.3 where a small UVA signal was detected through the front visors of aircraft with poor UVA attenuating windshields.

Side window blinds were seen to offer not only a larger coverage of the window area, but also superior UVA absorbing qualities to the front visors (section 8.4.4). The high levels of diffuse sunlight observed in the cockpit is strongly corroborated from the high levels of dissatisfaction with the standard aircraft fitted sunlight protection systems reported in the questionnaire (section 4.9.9) results. The number of non-standard strategies employed by pilots during flight (section 4.9.7) including the use of newspapers, checklists, charts, tray liners, jackets, seat and HUD covers demonstrate that a high proportion of pilots find the standard visors unfit for purpose and resort to using whatever is to hand to block sunlight during flight. Further, a small proportion of pilots have actively obtained additional sun glare protection and carry this in their flight bag. This is often in the form of a vehicle glare screen.

These previously undiscovered findings demonstrate that although front visors offer sufficient UVA and blue light attenuation properties, large areas of the windshield remain without protection and high levels of diffuse radiation are likely to be present in the cockpit. Therefore, aircraft manufacturers should attempt to install superior levels of sunlight protection in aircraft for the pilots in the form of greater flexibility of visor positioning and a larger area of front windshield protection. Dimmable electrochromic user operated tinted windows are available for aircraft cabin windows PPG Aerospace, 2009) for passenger comfort. To maintain safety in the situation of a loss of power, the window system defaults to a clear state. Although no details are given regarding the transmission properties when activated, this technology could also offer comprehensive cockpit protection for the pilot.

10.5 Pilot flying schedules

Professional pilots are limited to a maximum of 900 flying hours per annum (section 1.5.3). Two airlines and the helicopter operator participating in the research were questioned regarding the likely number of hours logged per annum of a full time employed pilot and additionally the amount of time spent operating during daylight hours.

A number of factors determine the annual number of daylight hours flown by the professional pilot.

1) Type of operation – One airline questioned relied more heavily on supplying flights to holiday destinations and the pilot workload was consequently more seasonal with busiest months being January to March and May to September. Pilot schedules would tend to be quietest from October to December when there are fewer daylight hours. The second airline approached operated flights to more cities and there was less seasonal variation of flights. The helicopter operator ran flights to offshore installations all year round.

2) Size of base – Both airlines had a relatively large presence at London Gatwick. Pilots based here would expect to accrue 100-150 hours more per annum than pilots based at other airports. The helicopter operator had the largest base at Aberdeen with pilots accruing approximately 50-100 hours more than those at the Shetland base and 150 hours more than those based at Norwich.

3) Number of waves per day – This is the number of return trips that the aircraft makes from the base per day. It is, to a certain extent, influenced by the airport operating hours and night time air traffic noise constraints. The number of waves gives an indication of the number of hours that the aircraft is flown during daylight hours. Both airlines generally operated 3 waves per day during the summer and 2 during winter months. On a 3 wave day, the first would leave from around 0500 to 0700 local. The second from around 1100-1300 local and the third from around 1800-2100 local. The helicopter operator normally conducted 3 waves starting around 0700 local. Occasional 4 wave days were conducted, but the operations were restricted by the airport closing at 2230 local.

4) Number of sectors flown per day – The flight crew would be scheduled to fly a certain number of sectors per day. For airline flights, this is often 2 sectors as was experienced on flights during data collection with the exception of flight 4 for which the crew had a stopover rest at Tobago. This airline had a mixture of long and short haul destinations. The longest 2 sector destination would be Egypt with a return flight time of approximately 11 hours and the longest long haul destination would be Goa at just under 11 hours. The other airline approached operated shorter sectors and pilots could be scheduled to fly between 2 and occasionally 6 sectors in a day.

Pilots based at London Gatwick flying for the airline operating more holiday routes average 700 hours per annum. This airline has mainly short haul routes but with some long haul routes. Pilots fly either short haul or a mixture of long and short haul. It is estimated that around 80% of short haul flying is conducted during daylight hours and around 60% of long haul flying is conducted during daylight hours. The second airline operates no long haul routes. Pilots based at London Gatwick fly around 870 hours per year with an overall estimate of 80-90% daylight flying. Both airlines questioned had a large base at London Gatwick and the estimates given are higher than the mean number of hours flown over the past year as declared by short haul pilot participants of the questionnaire (640+/-151 hours). Enquiries revealed that pilots operating on purely long haul routes would likely fly approximately 700 hours per annum. This concurs with the mean value from long haul pilots in the questionnaire (707+/-150 hours).

Pilots employed by the helicopter operator at Aberdeen would average around 700 hours per year. Due to airport operating hours and summer daylight hours in Aberdeen, it is estimated that 95% of flying is carried out during daylight hours. Based on the estimates given above, a short haul pilot would expect to fly at least 480 daylight hours per annum if operating from a smaller base and up to 780 daylight hours per annum from a larger base. The long haul pilot would fly approximately 420 daylight hours per annum and this could be less depending on pilot rotation and crew rest breaks on flights with 3 (or 4) pilots present. The average offshore helicopter pilot is likely to fly between approximately 520-670 daylight hours per annum.

Calculation of the average SED per hour across all aeroplane flights was 0.06 SED/hr (section 6.2.10). Based on this value, estimated annual exposure would be between 29 to 47 SED per annum for short haul pilots and approximately 25 SED per annum for long haul pilots. The average SED per hour across helicopter flights was 0.04 SED/hr giving an estimated annual exposure of 21- 27 SED. It should be noted that these figures are estimates and that more accurate data would be expected from a long term dosimetry study. Additionally, these estimates only take into account occupational exposure and would be less than the total annual exposure.

It can be seen from the results that the SED per hour calculations appear only marginally affected by the UVA attenuation properties of the windshield. This is most likely due to the erythema weighting function which is weighted towards shorter wavelengths including UVB. Therefore, there is little effect of increased levels of near visible UVA on SED values.

The estimated pilot occupational exposures do compare favourably with studies assessing annual exposure in indoor workers and gardeners in Denmark (median 132 and 224 SED respectively) (Thieden, 2008) and in mountain guides (mean cumulative annual exposure >1,000 SED per annum) (Moehrle et al, 2003). Median daily SED exposures for training athletes during summer months in Spain have been reported as 7.5, 8.1 and 14.5 for tennis players, hikers and runners respectively (Serrano et al, 2014). Construction workers in Spain were reported as receiving a median SED dose of 6.1 in the month of July (Serrano et al, 2013). It is recognised that those subject to outdoor exposure may be more likely to use sun cream and sunglasses.

Long haul pilots wear sunglasses significantly less than their short haul counterparts, which is thought to be due to the finding that this cohort has a higher mean age and a higher prevalence of a requirement for corrective spectacles. Long haul pilots are also the highest users of non-standard sunlight blocking strategies (section 4.9.7), most of which involve placement of an opaque material near or on the inside of the windshield to prevent direct sunlight. Although this practice was not observed on flight 4, it is likely that this action will also reduce ocular exposure to UVA and the blue light hazard. It is not known how effective this practice is in reducing ocular exposure compared to wearing sunglasses. However, it can be seen that long haul pilots undertake the lowest estimated number of daylight annual flying hours and it is likely that long haul pilots are more likely to receive a lower annual exposure than their short haul pilot counterparts.

The fact that helicopters operate at lower altitude than airline operations does not necessarily result in a lower UVA exposure for the pilot. Section 6.2.13.2 demonstrated that an equivalent ocular dose can be received by the helicopter pilot under certain conditions as discussed in section 6.3.1. As these helicopter pilots operate in aircraft with little or no fitted solar protection and without the opportunity to undertake non-standard sunlight protection strategies, it is feasible that a higher annual ocular dose could be received during flight by the helicopter pilot compared to the airline pilot particularly as sunglasses are less likely to be used. However, the annual variability of low altitude cloud compared to the conditions at high altitude does not make it possible to extrapolate these findings to an estimate of annual exposure even though a higher number of daylight flying hours are likely to be undertaken by the helicopter pilot compared to the long haul pilot.

Assuming that no solar eye protection is used, calculations show that short haul pilots should be considered at a risk of the highest annual exposure due to the higher number of daylight hours flown.

There are a number of factors which support the hypothesis that the occupational ocular lifetime exposure is likely to increase with time. As discussed, it is likely that newer aircraft will have poor UVA attenuating windshields and may utilise technologies such as HUDs. Newer aircraft designs are generally more efficient not only in fuel consumption but also in flight profiles, being able to attain a higher altitude in a quicker time than older aircraft designs. It is anecdotally reported that applicants are entering pilot training at a younger age. Although there are minimum ages for holding both medical certificate and licence (section 1.5.3), it was traditionally more common for airline flying to be considered a second career rather than for school leavers. Finally, airlines are likely to organise their flight operations to ensure that every pilot employee is utilised to the maximum benefit which in turn is likely to increase a pilot's flying hours towards the 900 hour per annum limit.

10.6 Ocular exposure levels

The data clearly demonstrate the difference between pilot exposure and that of an office worker during a normal eight hour working shift (section 7.3). Although a lower exposure in office workers may be expected, it would seem likely that the windows in the office building have good UVA attenuating properties as the calculated UVA dose remained relatively constant at different workstations including an office with no natural light. It would be reasonable to conclude that the source of the UVA signal detected is influenced by the fluorescent tube lighting present throughout the building. The office used with windows had horizontal slat blinds covering the entire window area and thus allowed good control of diffuse illumination with a subsequent reduced risk of glare symptoms.

It is recognised that the average outdoor worker is likely to receive a significantly higher ocular exposure than the average office worker however it was felt that, for the purposes of comparing populations of a similar socio-economic status, a comparison to office workers would be more appropriate. The office chosen, the CAA Safety and Airspace Regulation Group building, houses approximately 700 employees of which a number are professional pilots. The data presented is unlikely to reflect the range of occupational exposures of all office workers; however, this was not an aim of the study.

A summary of the UVA dose found in this research is shown in Table 10-a.

Aeroplane	UVA per hour J/m^2 (ahead)
good UVA atten	263
poor UVA atten	5160
Helicopter	
good UVA atten	196
poor UVA atten	7725
Office worker	290

Table 10-a Mean UVA dose per hour measured during flight for both windshield types in aeroplane and helicopter operations and office workers.

UVA dose per hour in aircraft with good UVA attenuating properties is comparable with office workstations measured and would not exceed ICNIRP recommended limits over an 8 hour period. A pilot operating an aeroplane with a poor UVA attenuating windshield and without ocular UV protection will, on average receive an ocular exposure in excess of ICNIRP recommended limits after 2 hours of flight. However, this was found to occur in less than 30 minutes after takeoff on flight 5 for an eyes ahead position and within 1 hour after takeoff for an eyes down position. This was mainly due to the combination of a poor UVA attenuating windshield, the position of the solar disc and high irradiance on the outbound sector.

Based on the considerations described above, a busy short haul pilot operating aircraft with poor UVA attenuating windshields could be expected to receive an additional 3.8×10^6 J/m^2 of UVA per annum over the office worker before any outdoor activities are taken into account. The risk of developing UVA related ocular pathology in any individual would have to take into account the estimated annual dose from outdoor activities which is likely to vary widely between individuals.

10.7 Pilot eye protection practices

Phase 1 revealed the prevalence of sunglass use and the typical types of sunglasses used in flight. There was a surprisingly even spread for the amount of time that sunglasses were used with similar numbers of pilots using sunglasses near constantly during daylight flying hours through to those pilots who never use sunglasses in flight. Clearly there is a population variation to bright light and glare tolerance which influences whether sunglasses are used. Factors such as degree of ocular pigmentation (Stringham and Hammond, 2007; Stringham and Hammond, 2008; Loughman et al, 2010a; Loughman et al, 2010b), age and the presence and type of ocular media changes (Vos, 2003) are likely to affect an individual's sensitivity to glare. Whilst many respondents are clearly comfortable using sunglasses to the extent that they do, a number of barriers to sunglass use were discovered including using corrective spectacles, difficulties interpreting instruments through a sunglass tint and comfort over prolonged periods particularly in the presence of the headset. It is reasonable to conclude that this group of pilots would wear sunglasses more during flight in the absence of these barriers.

It would be beneficial for detailed and targeted information to be drawn up and made available for pilots purchasing sunglasses. The range of sunglasses comfortably used by pilots in flight suggests that there is no common sunglass tint or manufacturer of sunglasses which would be preferred by all pilots performing any type of flight operation. It is therefore suggested that detailed generic guidelines be drawn up which include each of the main barriers raised in the questionnaire and helpful tips to avoid these issues. Suggested recommendations are made in the section 10.16.

It should also be important to recognise that many spectacle wearers may not wish to or may not feel the need to wear specific solar radiation protection during flight. It would therefore be beneficial to develop a lens with appropriate UVA protection and blue light hazard reducing properties which would not be classed as a sunglass tint and could be worn during night flying.

It should also be made clear within the information that, as discovered as part of this study, many cockpit windshields do not attenuate UVA sufficiently to offer sufficient ocular protection as defined by international guidelines and that further steps should be taken by the pilot to ensure adequate ocular protection. Adequate UVA protection from the aircraft windshield cannot be assumed.

10.8 Peripheral incident radiation

Aircraft windshield binocular field of visibility charts for Airbus A320 and A330 are described in section 1.5.6. These state the potential angular range of incident radiation during flight however, the charts do not take into account the use of visors or side blinds during flight.

Results from visor and blind transmittance (section 8.3) show that good UVA attenuation is achieved and, with the exception of the data from the Embraer 195 aircraft, less that 5% of blue light was found to be transmitted. No blinds were used on the side 'fixed window', further behind the pilot (Figure 1-j), during any flight. Indeed, it is possible that no blinds are fitted as standard for these windows.

It would be reasonable to expect that a well fitting pair of sunglasses would offer protection from the front windshield. Based on data in Figure 1-h and Figure 1-i, this would be to around 30-35° superiorly, 35° nasally, around 20° inferiorly and up to 45° temporally. However the edge of the sliding side window would exceed 100° temporally. Wrap-around sunglasses were the most prevalent style used and were worn by 37.6% of sunglass wearing pilots (see section 4.9.4). Without the use of the blinds, this type of sunglass would provide the optimum protection from radiation through the side window assuming they were well fitting.

Binocular field of visibility data for helicopters flown were not available. Due to the aircraft manoeuvrability and vision requirements for approach and landing, windshield area is extended inferiorly but would likely remain at around 100° to the pilot's eye temporally (Figure 10-c and Figure 10-d). No side window blinds were fitted on the helicopters flown. In the absence of high reflection from ground level, it is unlikely that radiation through the lower windows contributes significantly to ocular exposure. Intense reflected radiation through these lower windows could act as a glare source near the direction of gaze when viewing instruments and could be difficult for the helicopter pilot to manage.

Figure 10-c Lower windshield on Sikorsky s-92A helicopter

Figure 10-d Lower windshield on Aerospatiale AS332 Super Puma helicopter

Studies have demonstrated that the peripheral light-focusing (PLF) effect discussed in section 2.4 results in a peak intensity at the nasal limbus approximately 20 times that of the incident light and that an incident angle of around 120° is required to produce the maximal effect (Kwok et al 2003). High intensity incident radiation is likely to be encountered during flight at this angle as it will fall within the range of the pilot's side window. Results of the audit (section 4.14) showed a low prevalence of recorded pterygium (0.05%) in Class 1 licence holders. This is likely to be due to a number of reasons including the effective filtering of UVB by the windshields, the higher prevalence found of good UVA attenuating side windows, use of side blinds in bright conditions and their UVA attenuating qualities and use of wrap-around sunglasses. The PLF effect has also been reported to increase the risk of cortical cataracts, particularly in the lower nasal quadrant. Results from both audit and questionnaire were not able to distinguish type and position of reported cataracts. Kagami et al (2009) examined each participant using the slit lamp biomicroscope and found cortical cataracts to be the most common non-congenital type cataract. However, the location of the cataract was not reported.

The use of UV blocking contact lenses would help to reduce any PLF effect (Wolffsohn, 2013). Results from the questionnaire (section 4.9.2) show that of the contact lens wearing pilots, 30.9% knew that their contact lenses had UV blocking properties. Additionally, a higher prevalence of contact lens use was noted than reported in the general population of working age (section 4.11.1). This, together with calculated ocular UVA dose found on six of the ten flights undertaken, enforces the importance of promoting awareness amongst contact lens wearing professional pilots as to the benefits of lenses with a UV block.

10.9 Blue light data

The data do not indicate a risk to pilots of type II blue light retinal phototoxicity based on the ICNIRP guidelines. Although mean and maximum blue light weighted radiance was highest onboard aeroplane flights, the highest dose measured was approximately a quarter of the limit value recommended in ICNIRP. Further detailed task analysis may offer further refinement of blue light weighted radiance, however as discussed in section 6.1, if errors are present due to the criteria used in these calculations, it is most likely to have resulted in an over-estimation of blue light weighted effective radiance. It therefore follows that further analysis is unlikely to affect the overall outcome as, if anything, lower radiance values would result.

There is not thought to be a risk of type II retinal photochemical damage to the pilot due to repeated daily exposures during flight as ICNIRP (2013) state that long exposures should be considered as a series of separate 10,000 second events. This conclusion was reached by Roscoe and Diffey (1994) in their preliminary study measuring blue light during a one sector flight.

It is difficult to ascertain the effect to the retina of the increase in blue light received at altitude over a full career as a professional pilot. Although there is some evidence of the effect of longer term rhodopsin mediated type I blue light photochemical damage, there appears insufficient data to determine if an exposure limit should be recommended and if so what the limit should be. There is limited evidence of a cumulative effect of blue light exposure (see section 2.6) and a variation in susceptibility for retinal damage due to the circadian cycle (Duncan and O'Steen, 1985) which may be interrupted particularly in the long haul pilot.

This research has shown that the mean blue light weighted radiance was 4.1 times higher at altitude than on the ground for aeroplane flights. The similar calculated mean blue light weighted radiance increase on helicopter flights was 2.5 times higher at altitude.

All visor and side blinds measured demonstrated transmittance below 5% around 440nm with the exception of aircraft 13 which showed a transmittance of between 5-10% around 440nm for one front visor and one side blind (p.216). Although good attenuation properties are afforded, significant levels of diffuse radiation remain due to the area of front windshield not covered by a visor as discussed in section 10.3.

Pilots should be aware of increased dose of blue light weighted radiance at altitude. Results from sunglass transmittance measurements (sections 9.4.3 and 9.4.4) show that non-graduated tints and the top of graduated tints have transmittance values of 440nm radiation generally between 5-20%. This correlates to between 5-25 times signal attenuation.

The blue light hazard action spectrum is applied over the range 300-700nm but strongly weighted around 440nm (section 1.4.8). For the purposes of the following blue light attenuation figures, the attenuation of signal at 440nm has been applied as an approximation of blue light hazard reduction. It is recognised that a sunglass lens is likely to have lower transmission properties at shorter wavelengths and higher transmission properties at longer wavelengths.

A small number of uniform and graduated sunglasses (including RayBan, Oakley and Serengeti) were individually assessed as to the attenuation of the blue light hazard spectrum at each wavelength from 300-700nm. The resultant overall blue light hazard reduction was compared to the lens transmittance at 440nm. It was seen that the use of this wavelength point would underestimate actual blue light hazard reduction by between 0.2 to 8.8%.

Although a conservative estimate, if sunglass protection for the airline pilot was sought to reduce the average incident radiance at altitude to an equivalent average radiance for an unprotected eye at ground level, a transmittance of around 24% or less at 440nm should be selected. Based on the findings in sections 9.4.3 and 9.4.4, this would include all RayBan, Oakley and Serengeti sunglasses measured.

Results from the questionnaire shows that this covered 59.8% of the sunglass wearing cohort. Although these estimates represent the mean increase in blue light weighted irradiance measured at altitude, clearly there will be a large variation with higher levels experienced at times. However, as no risk has been found of shorter duration type II photochemical retinal toxicity, there is no evidence that sunglass protection from the highest signals found in flight would be necessary. There were two sunglasses measured which could reduce the maximum blue light weighted signal to an equivalent average radiance for an unprotected eye at ground level. These had a transmittance of less than 2.2% at 440nm and one pair of sunglass was specifically marketed for pilots.

Based on the results, the helicopter pilot would need to have a sunglass lens with transmittance of less than 40% at 440nm in order to reduce the average incident radiance at altitude to an equivalent average radiance for an unprotected eye at ground level. All sunglasses assessed met this criterion.

It has been demonstrated in sections 4.5.2.1 and 4.9.4 that the use of corrective spectacles is a barrier to sunglass use and that spectacle wearers use sunglasses significantly less than non spectacle wearers. A typical untinted lens materials such as CR39 has a high transmittance around 440nm. However, it is reported that the addition of a blue light blocking anti-reflection coating on a lens can reduce the incident signal by up to 25% (personal communication Norville, 07/05/14). The addition of this coating would offer a degree of blue light protection for the spectacle wearing pilot, although this effectiveness would likely be reduced where the lenses surface had damage such as scratching.

UK Driving standards currently stipulate that for night driving, spectacle lenses should not have a tint with a lower luminous transmittance than 75% (Fowler, 2011). EASA medical requirements state that: *"No more than one pair of spectacles shall be used to meet the visual requirements when exercising the privileges of the applicable licence(s)"*, that any correction required: *"be well-tolerated and suitable for aviation purposes"* and that *"a spare set of similarly correcting spectacles, for distant or near vision as applicable, shall be readily available for immediate use when exercising the privileges of the applicable licence(s)."* (EASA, 2013a) However there is no statement regarding a luminous transmittance requirement for night flying. ICAO state that: *"Tinted spectacles, prescription or otherwise, are for daytime use only and result in severe reduction of visual performance if used in twilight or darkness"* (ICAO, 2012) and it has been UK CAA guidance (CAA, 2008) that one pair of spectacle should be untinted.

A lens designed to meet a luminous transmittance of 80% but with bias toward short visible wavelength absorption could attain a reduced transmittance at 440nm. A lens such as this combined with a blue light blocking anti-reflection coating could potentially reduce the blue light hazard and be available to spectacle wearers for both day and night flying. In view of this and the results of this study, further investigation of the approval of this type of lens for use by pilots is recommended.

10.10 Sunglasses versus visors

All sunglasses showed less than 1% transmittance up to 380nm increasing in some cases marginally up to 400nm. They were able to provide sufficient UV attenuation such that the pilot would not be exposed to UVA radiation in excess of recommended guideline limits regardless of the length of flight, irradiance levels or windshield property. The visors measured also showed good UVA attenuation with minimal transmittance, although some visors showed an increased transmittance in the UVA range. However, only in a scenario where all incident light were filtered by a visor would sufficient protection from excess ocular exposure be afforded. As discussed in section 10.3, this cannot occur as the visor only partially covers the total windshield area and high diffuse irradiance levels may still present within the cockpit.

Similarly for protection from blue light, all sunglasses and visors measured would offer sufficient attenuation to ensure that exposure were no greater than that of the unprotected eye at ground level, assuming that no diffuse, unfiltered radiation were present. The visors measured generally offered greater attenuation of blue light compared to sunglasses with measured transmittance at 440nm generally less than 5%. While some sunglasses also showed similar transmittance values, others showed transmittance up to around 30% at 440nm.

Due to their positioning relative to the eye, sunglasses would always be expected to offer a superior level of ocular protection from non-ionizing radiation compared to visors. Significant levels of ocular irradiance may be received in the presence of a visor despite its adequate transmission properties.

10.11 Considerations for sunglasses

As described above, all sunglasses measured showed adequate ocular protection for the professional pilot from UVA and blue light received during flight. Were a pilot to be seated behind a good UVA attenuating windshield, there would be no requirement for additional protection in order to ensure UVA ocular exposure guidelines are not exceeded. However, as the majority of windshields measured were not good UVA attenuators, a degree of UVA protection in sunglasses would be required in order to ensure safe ocular protection. All fixed tint, graduated and polarised sunglasses met this requirement and it is reasonable to conclude that all sunglasses meeting ISO standards would provide sufficient UVA protection for the professional pilot. Additionally all sunglasses measured are able to provide a level of blue light hazard protection to the pilot which would be no worse than the average unprotected eye in the cockpit at ground level. To attenuate the mean blue light to levels comparable to that of the unprotected eye of an office worker in workstation 1 (office with windows and natural daylight), a sunglass lens with less than 2% transmittance at 440nm should be sought.

The International Standard for sunglasses state requirements for general use filters for the detection of signal lights for road use. The results from section 4.9.4 showed that pilots had no particular preference for a tint colour although the majority (86.8%)

used a sunglass with a grey (38.3%), brown (36.8%) or green (11.7%) tint. As it was found that all sunglasses measured provided adequate protection for the pilot, the other tint requirement should be that the tint colour should not interfere with the colour rendering ability of the pilot. As the colour vision standards for pilots are more stringent than for drivers (EASA, 2013b), it would seem prudent that a neutral tint for aviation continue to be promoted.

A number of other factors should be considered when selecting sunglasses. As discovered in sections 4.5.2.1 and 4.9.4, frame comfort and interaction with the headset is a strong factor for success with sunglasses. The frame therefore should be light with thin comfortable fitting sides over the ears. The sides of the sunglasses should not cause the headset cups to be pushed away from the ears. This is of particular consideration for the helicopter pilot where greater ambient noise is present during flight and a risk of noise induced hearing loss is present if not adequately protected. The helicopter pilot operating to off-shore sites also needs to ensure that any sunglasses used are secure when outside the aircraft with the rotors running such as when off-loading and on-loading passengers on oil platforms.

The sides of the sunglasses should be thin also to prevent any significant frame artefact induced visual field defect for the pilot. This is the case for any glasses (prescription or sunglasses) used in flight where a pilot is required to keep a look out scan outside for any conflicting traffic. Although being thin, the sunglass sides should not be too flexible such that they cannot be easily put on during flight with the pilot retaining one hand on the controls.

It is reassuring that when questioned, the most important factor for a pilot in sunglass selection was comfort in both frame and tint (section 4.9.4).
Wrap-around sunglass styles are inherently likely to offer good protection from peripheral radiation, however in sunglasses where the sides are also curved, there is likely to be more interference with the headset. Ground transmittance measurements have demonstrated that, where fitted, side window blinds provide good UVA attenuation and also cover almost the entire window area.

One of the main factors for not using sunglasses was the requirement to wear prescription corrective lenses. A lens material with good UVA blocking properties (e.g. Trivex) should be chosen for all spectacle wearing professional pilots. As discussed on page 267, the addition of a degree of protection from the blue light hazard could be incorporated and would require further work to be approved for night flying.

10.12 Recommendations for windshields

Currently, the pilot has no means to assess the windshield attenuation properties of a particular aircraft. This should be addressed.

One method for a pilot to assess the UVA blocking properties of a particular windshield would be to carry on board a UVA sensitive dosimeter. However, there is no UVA sensitive film that is as convenient to use and process as a polysulphone (UVB sensitive) dosimeter (Parisi et al, 2004). A number of UVA dosimeter materials have been proposed (Faneslow et al, 1983; Wong and Parisi, 1996; Turnbull and Schouten 2008), however there are difficulties with their processing after exposure (Paris et al,, 2004). There are dosimeter materials reported which are sensitive to both UVA and UVB (Diffey et al, 1977; Diffey and Davis, 1978). Wong and Parisi (1996) describe a system using four different types of UV sensitive polymer films to evaluate UVA exposure. The dosimeter proposed by Turnbull and Schouten (2008) measured levels of solar UVA in excess of 20,000 Jm^{-2}.

The use of a spectrometer by the pilot to assess each aircraft's windshield would be costly and impractical. An instrument such as the illuminance UV recorder used in this study has the potential to be used by the pilot to determine the UVA attenuating properties of a particular windshield. An approximately ten fold lower signal was recorded on the UV channel behind a good UVA attenuating windshield compared to a poor UVA attenuating windshield. However, further research would be required in order for guidelines to pilots to be issued if using this equipment.

It has been demonstrated that motor vehicle windshields transmit a degree of UVA and it has been recommended (Parisi et al, 2004) that UVA exposures that may be received whilst in a car are an important risk factor to consider when undertaking any human cancer risk assessment. An ultraviolet protection factor (UPF) for vehicle windscreens has been suggested based on the transmission properties of the material weighted with erythemal action spectrum and uses a similar principle to sun protection factor (SPF) used by sunscreens (Paris et al, 2004). A UPF of 100 transmits 1% of erythemal UV and absorbs 99%. However there is no significant additional protective benefit in UPF values beyond 50 and laminated windshields are reported to have UPF values in excess of 75 (Parisi et al, 2004). This finding concurs with relatively low in flight SEDs calculated as UPFs are weighted with the erythemal action spectrum. It is suggested that adopting UPF for aircraft windshield is not appropriate as it would mask the effect of the difference in UVA transmittance between windshields due to much lower spectral weighting of UVA in UPF values. As irradiance levels may be high during flight, this potentially small difference in UPF may result in a large difference in UVA exposure. It is recommended that while emphasising that all aircraft windshields should offer good erythemal protective properties, an identification system should be developed to provide the pilot with information as to the UVA blocking properties of a particular windshield.

Long pass filters are available which increase cut off wavelengths. They are generally made from materials such as mylar or cellulose acetate (Parisi et al, 2004) and are sometimes available as thin, flexible rolls which can be used to cover larger areas (Edmundoptics, 2014). However these filters are reported to degrade with time and need regular replacement (Parisi et al, 2004).

While an optimum solution would be to replace all poor UVA attenuating windshields with windshields of better UVA attenuation, this is unlikely to be considered a feasible solution based on cost and the lack of acute health effects. Therefore, in the absence of this, it is recommended that windshields should be assessed and labelled so that every pilot using that aircraft has the opportunity to tailor their ocular protection strategies accordingly.

This would additionally raise awareness within the pilot population of the risk of long term UVA exposure to health as repetitive exposures to relatively low erythemal UV is reported to have an cumulative effect which can produce early skin alterations indicative of skin damage (Lavker et al 1995, Lavker and Kaidbey 1997, Lowe et al 1997), premature photo-aging and wrinkling. Kligman and Gebre 1991 report that UVA causes biochemical changes in mouse skin and authors including Wang et al (2001) have linked UVA exposure to an increased risk of malignant melanoma formation.

In the absence of this recommendation being implemented, pilots have to assume that, without ocular protection, their eyes may be exposed to UVA above recommended ICNIRP guideline limits even on relative short sectors. Pilots should be aware that this may easily occur during flights which do not feel bright and that subjective assessment of sunlight conditions would not be a reliable means of determining whether to use solar eye protection. Pilots should also be informed that sunglasses or UV absorbing contact lenses will provide a better control of UV reaching the eye than the use of aircraft visors.

10.13 Infrared

Full infrared spectra were not measured and no data regarding exposure to infrared radiation has been presented. However, there was no reporting of thermal discomfort in section 4.9 and therefore solar infrared is unlikely to present a health concern.

10.14 Further research

A number of new findings have emerged from this study. It has also highlighted gaps in existing knowledge which further research may be able to address.
As discussed in section 2.7, the prevalence of non-ionising radiation related ocular pathology in professional pilots compared to a general population has not been established. It was not the aim of this study to determine this. However, this research has shown that there is an increased risk present from the high levels of UVA irradiance measured in the cockpit during flight. The research has established that the level of ocular exposure is complex and is affected by a number of factors. The traditional view that ocular dose is related to altitude and length of flight has been shown to be false. This is clearly demonstrated by higher UVA ocular irradiance and dose during some short helicopter flights compared to a nine hour trans-Atlantic flight. It has been demonstrated that the type of aircraft windshield installed is the main factor for UVA exposure but significant UVA transmittance by some windshields can be compensated by sunglass wear. However, for a number of reasons identified in this research there are many pilots not using sunglasses during flight. Additionally, it is the busy short haul pilot who will accrue the greatest number of daylight flying hours annually. A study investigating the prevalence of UV related pathology in pilots could therefore be more appropriately targeting using this new knowledge.

The use of a large cohort of older, retired professional pilots may reveal that a career long exposure places the individual at higher risk than age matched controls. Identification of sufficient numbers of suitable participants may be problematic and recruitment techniques such as respondent-driven sampling (Heckathorn, 1997) may be utilised to identify this population. The finding of this research that older aircraft windshields are likely to be better UVA attenuators may affect the prevalence of cataract in this population. However, a longitudinal study may identify an increase in cataract prevalence over time as pilots may spend more of their career behind a poor UVA attenuating windshield. The levels of blue light hazard are less likely to be affected by windshield type. With increasing evidence of the role of blue light in damage to photoreceptors (sections 2.4 to 2.6), the prevalence of macular degeneration in retired pilots together with their flying history would be of great interest.

Were an industry standard windshield labelling system to be implemented to inform the pilot of the UVA attenuating properties of a particular windshield, independent research would be recommended in order to evaluate the effectiveness of such a scheme.

Certain assumptions, discussed in section 7.1, have had to be made regarding the blue light hazard data and the calculations have likely produced a conservative estimate. While complex scenario testing and data re-analysis may produce a more accurate estimate, this would still show the exposure to be within recommended guideline limits. Any future changes to recommended guideline limits including recommendations for repeat exposures could be applied retrospectively to the existing data.

There is strong evidence of an increased prevalence of melanoma in the pilot population (Hammer et al, 2009; Sanlorenzo et al, 2014; dos Santos Silva et al, 2013). There is also increasing evidence of the separate and particular role that UVA plays in development of melanoma (Wang et al, 2001; Mitchell and Fernandez, 2012; Autier et al 2011). Although dos Santos Siva et al (2013) found occupation type (pilot or air traffic controller) to be a poor predictor of prevalence, this was without the knowledge of the differing windshield transmission properties of aircraft. The particular filtered spectrum of high intensity irradiance of the less energetic part of UVA found in the cockpit could assist in the development of a UVA melanoma action spectrum. Although erythemal hazard ratios were found to be low, these are heavily weighted toward UVB (section 1.4.8). A UVA melanoma action spectrum could be easily applied to existing data.

A large and repeated variation particularly in short wavelength visible light affects melatonin production (Lockley et al 2003). The data show that this scenario could occur in flight with large changes in blue light between ground level and altitude. Melatonin is a hormone produced by the pineal gland and is present in humans. It is known to influence the regulation of circadian rhythm and it is affected by high irradiance conditions which suppress its release. This, in turn, delays the onset of sleep and may lead to fatigue. Additionally, the repeated cycle of low and bright conditions as may be found during a shift of a short haul pilot flying a number of daily sectors may increase the risk of fatigue.

10.15 Appraisal of research

The research described in this thesis sought to gain insight into the occupational risk of ocular exposure to the professional pilot. Following careful information gathering and questionnaire preparation, information regarding the issues of sunlight in the cockpit, eye protection strategies used by professional pilots and barriers to the use of sunglasses has been elicited from nearly 3,000 current professional pilots. This represents a significant proportion of the UK professional pilot population and gives a high level of confidence to data validity. It is recognised that participants were likely to be BALPA members as this was the organisation through which the survey was promoted. It is not known if this population is different to the overall UK professional pilot population or indeed if differences are present in professional pilots worldwide. However, not only have clear themes arisen from these data but the findings have been invaluable in informing the other phases of the project.

Large amounts of in flight spectral data have been collected using equipment which has been prepared and calibrated to a robust standard. A range of flights on various aircraft types have been undertaken with the goal of determining the range of likely irradiance present during flight. A small number of spectrometer readings had to be discarded due to signal saturation. Here, irradiance calculations were based on data immediately before and after signal saturation. A series of dark readings taken in controlled conditions have been applied to the data for the occasions where an intermittent shutter fault was present. This resulted in irradiance calculations which were consistent with functioning shutter data.

Further data collection of aircraft windshield transmittance at ground level from a number of aircraft types has assisted greatly in determining those aircraft in which high ocular UVA exposures are likely. These measurements were taken in situ and as discussed in section 8.5, some data were discarded due to likely variation in source intensity during data collection. Additionally, it is acknowledged that there was a relatively low UV signal present. However, using these data, new knowledge of the prevalence of the use of eye protection strategies has been combined with the transmission properties of typical visors and sunglasses to evaluate the ocular UV and blue light dose received in flight.

Using the research data collected together with additional data such as MORS and typical pilot flight schedules, has enabled a picture to be built of the pilot ocular risk with regard to occupational exposure to short wavelength radiation based on best current knowledge of the ocular effects and safe recommended doses to minimise the risk of permanent ocular damage.

The diagrammatic summary of the research on p.57 shows how the results from various components of the research have been used to inform other stages and to draw final conclusions. At the time of writing, there has been no published work during the period of this research directly attempting to address this research question.

10.16 Conclusions

This research has found that UVB is blocked effectively by the aircraft windshield even in conditions of high overall incident irradiance. This concurs with the results from previous studies. However this study has, for the first time, established significant levels of UVA exposure on most flights. Pilot UVA exposure is highly reliant on the type of windshield fitted on the aircraft. Two similar aircraft of the same type may have different windshield transmission properties. One will attenuate sufficient UV such that an unprotected eye would not receive a dose beyond the daily recommended limit during flight. The other may cause the recommended ocular dose to be exceeded within ½ hour of flight. The pilot has no means to visually assess the windshield to determine its UV transmission properties. It is therefore recommended that the pilot should assume poor UVA attenuation as a minority of the aircraft measured showed windshields with good UVA attenuation and these were generally older registered aircraft.

During aeroplane flights, there was a 4.1 times greater mean blue light hazard signal at altitude compared to at ground level. The calculated ocular exposure level fell well below limits at which a risk of type II retinal photochemical damage may occur. However, the effect to the retina of repeated cyclic doses during different phases of the circadian cycle over a long term lifetime flying career is not known.

This research has investigated solar eye protection habits of professional pilots and has uncovered the barriers present to using sunglasses, the issues with managing bright sunlight on the flight deck and the range of practices to block sunlight during flight. From an ocular exposure perspective, the pilots most at risk will be those who use sunglasses minimally and who operate aircraft with poor UVA attenuating windshields. Individual risk assessment of ocular exposure is difficult without knowledge of the windshield properties of all aircraft flown by a particular pilot and number of daylight hours flown. From the results of this research, all sunglasses used by pilots are likely to provide adequate occupational ocular protection from UVA in flight and will ensure that recommended ocular exposure limits are not exceeded. As the risk to pilots of retinal photochemical damage through long term lifetime blue light hazard exposure is uncertain, a minimum safe level of blue light hazard protection required in sunglasses cannot be ascertained. However, the research has demonstrated that sunglass filters are likely to reduce the mean ocular exposure to the blue light hazard to at least the mean level expected on the ground without protection.

There is a level of pilot misconception regarding UV exposure which is also likely to be held in the general population. Pilot education should be considered an important tool. Not only should the raising of awareness of the research findings be undertaken, whilst also addressing the misconceptions such as the protection afforded by thick windshields and the measure of skin tanning as a measure of overall UV exposure, but also the recommendation of practical strategies to reduce ocular exposure.

The results show that the prevalence of non-ionising radiation related ocular pathology is low however it is recognised that it may not present within the working career of pilot. Strong evidence suggests a higher prevalence of melanoma in pilots and further evidence links UVA with increased risk of melanoma formation. The data collected in this research could be used to assess likely skin exposure in flight to any recommended guideline limits.

As the use of spectacle correction is a barrier to sunglass use, active steps can be taken to ensure that optimum UV protection is incorporated into the spectacle wearer's lenses. Assessment of the feasibility of promoting a spectacle lens with additional blue light hazard protection which is approved for night flying should be investigated.

Based on the results of this research, a series of recommendation are made to different groups and organisations:

1) The CAA should use the results of this research to update their website guidance materials as this is a key source of information to pilots and industry. The results could also be disseminated to pilots and industry through CAA publications whilst specialists involved in Aviation Medicine could be informed through presentation at international conferences.

2) There are a number of key messages to be delivered to the pilot population. Pilots must be made aware that windshields may transmit significant levels of UVA which may cause ocular exposure in excess of recommended limits within 30 minutes of flight unless eye protection is used. The visual inspection of a windshield will not reveal which are good or poor UVA attenuators. Any sunglass conforming to national or international standards will offer adequate UV protection and reduce harmful radiation to within recommended limits. Graduated tints are useful for pilots and help to ensure that sunglasses can be worn successfully during flight. Well fitting, lightweight frames with thin sides should help to ensure good headset compatibility, particularly for helicopter pilots. Pilots should consider taking a headset when trying sunglasses to assist appropriate selection and fitting.

3) Eye healthcare professionals should be able to make a number of recommendations to their pilot patients. The promotion of graduated tints and frame fit as described above is recommended. Additionally, optometrists and dispensing opticians should recommend a lens material which offers good UVA attenuation for spectacle wearing pilots. All contact lens wearing pilots should be offered a lens with UV blocking properties.

4) Windshield manufacturers should manufacture all new windshields with good attenuation up to 400nm and place information on existing windshields as to

their particular UVA attenuation properties. As the industry regulator, the CAA should be instrumental in ensuring this change occurs by using the evidence presented in this research.

5) Aircraft manufacturers should place greater emphasis on designing blinds and filters which offer greater windshield coverage as this research has found a high use of additional non standard protection strategies and poor ratings by pilots of the current aircraft standard systems. The research has shown that some aircraft types offer greater overall light attenuation than others.

6) As any change to aircraft sun visor design is likely to take some years, airlines should ensure that existing visors are serviceable and can be used in flight and should consider providing pilots access to further protection such as stick on visors in the cockpit. Additionally, instrument screen brightness settings should not be limited as this is likely to discourage pilot sunglass use.

This is an important piece of research as it has discovered a risk to pilot eye health through UVA exposure during flight. While the blue light hazard measured is within recommended guidelines limits for exposure, the typical increase at altitude has been established. Although the effects of lifetime exposure remain uncertain, the effect of typical sunglasses to reduce pilot ocular exposure has been quantified. In order to reduce the ocular exposure risk, a number of practical and achievable recommendations have been made.

References

Aeroshade Technologies [no date] *Aeroshade Technologies cockpit sunshades.* [Online] from Aeroshade Technologies: http://www.aero-shade.com/home_013.htm [Accessed 04-09-2014].

Agilent Technologies (1997) *Measuring the Stray Light Performance of UV-visible Spectrophotometers - Technical Note.* [Online] from Agilent Technologies: http://www.chem.agilent.com/Library/technicaloverviews/Public/59659503.pdf [Accessed 04-09-2014].

Airbus (2012) *A320 aircraft characteristics, airport and maintenance planning.* Sep 30/85, rev Jun 01/12.

Airbus (2014) *A330 aircraft characteristics, airport and maintenance planning.* Jan 01/93, rev Jan 01/14.

Albert, D.M., Neekhra, A., Wang, S., Darjatmoko, S.R., Sorenson, C.M., Dubielzig, R.R. and Sheibani, N. (2010) Development of choroidal neovascularization in rats with advanced intense cyclic light-induced retinal degeneration. *Archives of Ophthalmology*, 128, (2) 212-222.

Algvere, P.V., Marshall, J. and Seregard, S. (2006) Age-related maculopathy and the impact of blue light hazard. *Acta Ophthalmologica Scandinavica*, 84, (1) 4-15.

Ambach, W., Blumthaler, M. and schopf, T. (1993) Increase of biologically effective ultraviolet radiation with altitude. *Journal of Wilderness Medicine*, 4, (2) 189-197.

Anders, A., Altheide, H.J., Knalmann, M. and Tronnier, H. (1995) Action spectrum for erythema in humans investigated with dye lasers. *Photochemistry and Photobiology*, 61, (2) 200-205.

Andrews, D.G. (2000) *An introduction to Atmospheric Physics.* Cambridge: Cambridge University Press.

Asbell, P.A., Dualan, I., Mindel, J., Brocks, D., Ahmad, M. and Epstein, S. (2005) Age-related cataract. *Lancet*, 365, (9459) 599-609.

Augustin, A.J. (2014) Reliable UV-Light Protection in Intraocular Lenses - Scientific Rationale and Quality Requirements. *Klinische Monatsblatter fur Augenheilkunde*, 231, (9) 901-908.

Australian/New Zealand Standard. (2003) AS/NZS 1067:2003. *Sunglasses and fashion spectacles.*

Autier, P., Dore, J.F., Eggermont, A.M. and Coebergh, J.W. (2011) Epidemiological evidence that UVA radiation is involved in the genesis of cutaneous melanoma. *Current Opinion in Oncology*, 23, (2) 189-196.

Bachelor, M.A. and Bowden, G.T. (2004) UVA-mediated activation of signaling pathways involved in skin tumor promotion and progression. *Seminars in Cancer Biology*, 14, (2) 131-138.

Baczynska, K.A. and Khazova, M. (2014) Methods of dark signal determination for CCD array spectroradiometers in solar UVR measurements. *Radiation Protection Dosimetry,* pp1-7 [Online] DOI: 10.1093/rpd/ncu191 [Accessed 15/09/2014].

Bais, A.F., Blumathaler, M., Webb, A.R., Groebner, J., Kirsch, P.J., Gardiner, B.G., Zerefos, C.S., Svenoe, T., & Martin, T.J. (1997) Spectral UV measurements over Europe within the second Eurpoean stratospheric Artic and midlatitude experiment activities. *Journal of Geophysical Research*, 102, (D7) 8731-8736.

Bendik, I., Friedel, A., Roos, F.F., Weber, P. and Eggersdorfer, M. (2014) Vitamin D: a critical and essential micronutrient for human health. *Frontiers in Physiology*, 5, 248.

Bennett A.G. (2007) *Bennett and Rabbetts' Clinical Visual Optics.* 4th ed. London: Butterworth-Heinemann.

Bernhard, G. and Seckmeyer, G. (1999) Uncertainty of measurements of spectral solar UV irradiance. *Journal of Geophysical Research*, 104, (D12) 14321-14345.

Blumthaler, M. (1993) "Solar UV Measurements," *In UV-B Radiation and Ozone Depletion, Effects on Humans, Animals, Plants, Microrganisms and Materials*, F. Urbach, ed., Kansas: Valdenmar Publishing Co.

Blumthaler, M., Ambach, W., and Ellinger R. (1997) Increase in solar UV radiation with altitude. *Journal of Photochemistry and Photobiology*, B: Biology 39[2], 130-134. 1997.

Bogner, A., Littig, B. and Menz, W. (2009) *Interviewing experts.* Basingstoke: Palgrave MacMillan.

Bowling, A. (2009) *Research Methods in Health*. 3rd ed. Buckingham: Open University Press.

Breitenbach, R.A., Swisher, P.K., Kim, M.K. and Patel, B.S. (1993) The photic sneeze reflex as a risk factor to combat pilots. *Military Medicine*, 158, (12) 806-809.

Brilliant, L.B., Grasset, N.C., Pokhrel, R.P., Kolstad, A., Lepkowski, J.M., Brilliant, G.E., Hawks, W.N. and Pararajasegaram, R. (1983). Associations among cataract prevalence, sunlight hours, and altitude in the Himalayas. *American Journal of Epidemiology*, 118, (2) 250-264.

Brown, N.A. (1993) The morphology of cataract and visual performance. *Eye (London)*, 7 (Pt 1), 63-67.

Brown, N. P. and Bron, A. J. (1996) *Lens Disorders: A Clinical Manual of Cataract Diagnosis*. Oxford: Butterworth-Heinemann.

Caruso & Freeland [no date] *Pilot sunglasses*. [Online] from Caruso & Freeland: http://www.carusofreeland.com/en/3/2/pilots.html [Accessed 09-09-2014].
Chandler, H. and Nichols, J. (2011) UV protection with contact lenses. *Optometry Today*, [Online] from Optometry Today: http://www.optometry.co.uk/uploads/articles/chandler_nichols_april_2011.pdf [Accessed 05-09-2014].
Charman, W.N. (1989) The path to presbyopia: straight or crooked? *Ophthalmic and Physiological Optics*, 9, (4) 424-430.
Chorley, A., Evans, B., and Benwell, M. (2011) Civilian pilot exposure to ultraviolet and blue light and pilot use of sunglasses. *Aviation, Space and Environmental Medicine*, 82(9), 895–900.
Chorley, A., Evans, B., and Benwell, M. (2013) Solar eye protection habits of civilian professional pilots. *Medecine Aeronautique et Spatiale*., 54(202), 61–67.
Chorley, A., Higlett, M., Baczynska, K., Hunter, R., and Khazova, M. (2014) Measurements of Pilots' Occupational Solar UV Exposure. *Photochemistry and Photobiology*, 90(4), 935–940.
CIE (International Commission on Illumination) (1986) Photoconjunctivitis. *CIE J.*, 5, (1) 24-28.
CIE (International Commission on Illumination) (1986) Photokeratitis. *CIE J.*, 5, (1) 19-23.
CIE (International Commission on Illumination) (1998) *Erythemal reference action spectrum and standard erythemal dose.* Vienna: CIE.
Citek, K. (2008) Anti-reflective coatings reflect ultraviolet radiation. *Optometry*, 79, (3) 143-148.
Citek, K., Andre, B., Bergmanson, J., Butler, J. J., Chou, B. R., Coroneo, M. T., Crowley, E., Godar, D., Good, G., Pope, S. J. and Sliney, D. (2011) *The eye and solar ultraviolet radiation: New understandings of the hazards, costs, and prevention of morbidity. Report of a round table*. Salt Lake City, UT, USA: Essilor.
Ciulla, T.A. and Hammond, B.R., Jr. (2004) Macular pigment density and aging, assessed in the normal elderly and those with cataracts and age-related macular degeneration. *American Journal of Ophthalmology*, 138, (4) 582-587.
Civil Aviation Authority [no date]. *Spectacle frame and lens choice*. [Online] from Civil Aviation Authority: http://www.caa.co.uk/default.aspx?catid=49&pagetype=90&pageid=9247 [Accessed 05-09-2014].
Civil Aviation Authority (1992) *DORA report 9120: The CAA aircraft noise contour model; ANCON version1.* [Online] from Civil Aviation Authority:

https://www.caa.co.uk/application.aspx?catid=33&pagetype=65&appid=11&mode=detail&id=760 [Accessed 05-09-2014].

Civil Aviation Authority (2003) *CAP 371 The avoidance of fatigue in aircrews: Guide to requirements.* (Section C Annex A 22.1). [Online] from Civil Aviation Authority: http://www.caa.co.uk/docs/33/cap371.pdf [Accessed 04-09-2014].

Civil Aviation Authority (2007) *Schedule 8. Flight crew of aircraft: licences, ratings, qualifications and maintenence of licence privileges*. (part A, section 1) [Online] from Civil Aviation Authority: http://www.caa.co.uk/docs/1580/NPPL%20Schedule%208%20Amendment%2015%20Jan%2007%20-%20Public%20Release%20v%201%200%200.pdf [Accessed 04-09-2014].

Civil Aviation Authority (2008) *Guidance on using sunglasses*. [Online] from Civil Aviation Authority: http://www.caa.co.uk/default.aspx?catid=49&pagetype=90&pageid=9244 [Accessed 04-09-2014].

Civil Aviation Authority (2012) *UK CAA medical certificate validity table.* [v4.3] [Online] from Civil Aviation Authority: http://www.caa.co.uk/docs/1859/Medical%20Certificate%20Validty%20Table.pdf [Accessed 04-09-2014].

Civil Aviation Authority (2013) *CAP 804. Flight Crew Licencing: Mandatory requirements, policy and guidance*. (Section 4 Part A p.7 FCL065). [Online] from Civil Aviation Authority: http://www.caa.co.uk/docs/33/CAA_CAP%20804.pdf [Accessed 04-09-2014].

Civil Aviation Authority (2014) *UK airline statistics: 2013 - annual*. [Online] from Civil Aviation Authority: http://www.caa.co.uk/default.aspx?catid=80&pagetype=88&sglid=1&fld=2013Annual [Accessed 09-09-2014].

Connolly, E.E., Beatty, S., Thurnham, D.I., Loughman, J., Howard, A.N., Stack, J. and Nolan, J.M. (2010) Augmentation of macular pigment following supplementation with all three macular carotenoids: an exploratory study. *Current Eye Research*, 35, (4) 335-351.

Connolly, E.E., Beatty, S., Loughman, J., Howard, A.N., Louw, M.S. and Nolan, J.M. (2011) Supplementation with all three macular carotenoids: response, stability, and safety. *Investigative Ophthalmology and Visual Science*, 52, (12) 9207-9217.

Coroneo, M. (2011) Ultraviolet radiation and the anterior eye. *Eye and Contact Lens*, 37, (4) 214-224.

Cruickshanks, K.J., Klein, B.E. and Klein, R. (1992) Ultraviolet light exposure and lens opacities: the Beaver Dam Eye Study. *American Journal of Public Health*, 82, (12) 1658-1662.
Cruickshanks, K.J., Klein, R. and Klein, B.E. (1993) Sunlight and age-related macular degeneration. The Beaver Dam Eye Study. *Archives of Ophthalmology*, 111, (4) 514-518.
Cruickshanks, K.J., Klein, R., Klein, B.E., and Nondahl, D.M. (2001) Sunlight and the 5-year incidence of early age-related maculopathy: the beaver dam eye study. *Archives of Ophthalmology*, 119, (2) 246-250.
Dain, S.J., Wood, J.M. and Atchison, D.A. (2009) Sunglasses, traffic signals, and color vision deficiencies. *Optometry and Vision Science*, 86, (4) e296-e305.
Dain, S.J., Ngo, T.P., Cheng, B.B., Hu, A., Teh, A.G., Tseng, J. and Vu, N. (2010) Sunglasses, the European directive and the European standard. *Ophthalmic and Physiological Optics*, 30, (3) 253-256.
Darzins, P., Mitchell, P. and Heller, R.F. (1997) Sun exposure and age-related macular degeneration. An Australian case-control study. *Ophthalmology*, 104, (5) 770-776.
Daumont, D., Brion, J., Charbonnier, J. and Malicet, J. (1992) Ozone UV Spectroscopy I: Absorption Cross-Sections at Room Temperature. *Journal of Atmospheric Chemistry*, 15, 145-155.
Davis, A., Deane, G.H. and Diffey, B.L. (1976) Possible dosimeter for ultraviolet radiation. *Nature*, 261, (5556) 169-170.
Delcourt, C., Cristol, J.P., Tessier, F., Leger, C.L., Michel, F. and Papoz, L. (2000) Risk factors for cortical, nuclear, and posterior subcapsular cataracts: the POLA study. Pathologies Oculaires Liees a l'Age. *American Journal of Epidemiology*, 151, (5) 497-504.
Denscombe M. (2006) Web-based questionnaires and the mode effect: An evaluation based on completion rates and data contents of near-identical questionnaires delivered in different modes. *Social Science Computer Review*, 24[2], 246.
Denscombe M. (2007) *The good research guide: for small-scale social research projects*. 3rd ed. Maidenhead: Open University Press.
Diffey, B.L., Davis, A., Johnson, M. and Harrington, T.R. (1977) A dosimeter for long wave ultraviolet radiation. *British Journal of Dermatology*, 97, (2) 127-130.
Diffey, B.L. and Davis, A. (1978) A new dosimeter for the measurement of natural ultraviolet radiation in the study of photodermatoses and drug photosensitivity. *Physics in Medicine and Biology*, 23, (2) 318-323.

Diffey, B.L. and Roscoe, A.H. (1990) Exposure to solar ultraviolet radiation in flight. *Aviation, Space and Environmental Medicine*, 61, (11) 1032-1035.

Dos Santos Silva, I, De Stavola, B., Pizzi, C., Evans, A.D. and Evans, S.A. (2013) Cancer incidence in professional flight crew and air traffic control officers: disentangling the effect of occupational versus lifestyle exposures. *International Journal of Cancer*, 132, (2) 374-384.

Drucker, A.M. and Rosen, C.F. (2011) Drug-induced photosensitivity: culprit drugs, management and prevention. *Drug Safety*, 34, (10) 821-837.

Dully Jr., F.E. (1990) Pilot's Sunglasses: Mystique or Mandate. *Human Factors and Aviation Medicine,* 37[2], 1-4.

Duncan, T.E. and O'Steen, W.K. (1985) The diurnal susceptibility of rat retinal photoreceptors to light-induced damage. *Experimental Eye Research*, 41, (4) 497-507.

Edmund Optics Ltd. (2014) *Flexible thin film UV filters*. [Online] from Edmund Optics Ltd: http://www.edmundoptics.co.uk/optics/optical-filters/longpass-edge-filters/flexible-thin-film-uv-filters/1873 [Accessed 10-09-2014].

Eire Aviation Inc. [no date] *Roller blinds / shades and sun visors*. [Online] from Eire Aviation Inc: http://www.erieaviation.com/rollerblinds.htm [Accessed 04-09-2014].

Encyclopaedia Britannica [no date] *Fraunhofer Lines*. [Online] from Encylcopaedia Britannica: http://www.britannica.com/EBchecked/topic/217627/Fraunhofer-lines [Accessed 22-08-2014].

Ernsting J., Nicholson A., and Rainford D. (2000) *Aviation medicine*. 3rd ed. Oxford: Butterworth Heinemann.

Estupinan, J.G., Raman, S., Crescenti, G.H., Streicher, J.J. and Barnard, W.F. (1996) Effects of cloud and haze on UV-B radiation. *Journal of Geophysical Research*, 101, (D11) 16807-16816.

European Aviation Safety Agency (2013a) *Notice of proposed amendment 2013-15*. (MED.B.070(h)).

European Aviation Safety Agency (2013b) *Notice of proposed amendment 2013-15*. (MED.B.075(a - b)).

European Commission. (1995) *Air pollution research report 53: Setting standards for European ultraviolet spectroradiometers*. Luxemberg: European Commission.

European Commission (2006) *Directive 2006/25/EC 'Artificial Optical Radiation'*. Luxemberg: European Commission.

Facius, R. (2006) No evidence for the causation by cosmic radiation of nuclear cataracts in pilots. *Archives of Ophthalmology*, 124, (9) 1369-1370.

Fanselow, D.L., Pathak, M.A., Crone, M.A., Ersfeld, D.A., Raber, P.B., Trancik, R.J. and Dahl, M.V. (1983) Reusable ultraviolet monitors: design, characteristics, and efficacy. *Journal of the American Academy of Dermatology*, 9, (5) 714-723.

Federal Aviation Administration [no date] *Sunglasses for pilots: Beyond the image*. [Online] from FAA: http://www.faa.gov/pilots/safety/pilotsafetybrochures/media/sunglasses.pdf [Accessed 04/09/2014].

Federal Aviation Administration (1976) *Advisory Circular 65.15A*. [Online] from Federal Aviation Administration: http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/0/66ab237baf7184a0862569f1005f7733/$FILE/Chapter%207.pdf [Accessed 04-09-2014].

Federal Aviation Administration (2003) *Advisory Circular 25.775-1. Windows and windshields*. [Online] from Federal Aviation Administration: http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC25-775-1.pdf [Accessed 04-09-2014].

Fitzpatrick, T.B. (1986) Ultraviolet-induced pigmentary changes: benefits and hazards. *Current Problems in Dermatology*, 15, 25-38.

Flick, U. (2009) *An Introduction to qualitative research*, 4th ed. London: SAGE publications Ltd.

Fowler, C. (2011) Driving and vision: part 4 - dispensing to drivers. *Optician,* (18/02/11) pp32-35 [Online] available from: https://s3-eu-west-1.amazonaws.com/rbi-communities/wp-content/uploads/importedimages/p4.pdf [Accessed 09-09-2014].

Furusawa, Y., Suzuki, K. and Sasaki, M. (1990) Biological and physical dosimeters for monitoring solar UV-B light. *Journal of Radiation Research*, 31, (2) 189-206.

Galle B., Oppenheimer C, Geyer A., McGonigle A.J.S., Edmonds M. and Horrocks L. (2003) A miniaturised ultraviolet spectrometer for remote sensing of SO2 fluxes: a new tool for volcano surveillance. *Journal of Volcanology and Geothermal Research*, 119, (1-4) 241-254.

Gannon, M. (2013) *Sun's 2013 Solar Activity Peak Is Weakest in 100 Years*. [Online] from space.com: http://www.space.com/21937-sun-solar-weather-peak-is-weak.html [Accessed 22-8-2014].

Geiss, O. (2003) *Manual for polysulphone dosimeters, Characterisation, handling and application as personal UV exposure devices EUR 20981 EN*. [Online] from European Commission: http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/1227/1/EUR%2020981%20EN.pdf. [Accessed 08-09-2014].

Gelling, L. (2014) When to use mixed methods. *Nurse Researcher*, 21, (4) 6-7.
GFK (2013) *Optics Panel Market retail audit 2013*.
Gilbert, P. (2014) Material changes - plastic lenses of the last decade. *Optometry Today*, 14/02/14, pp46-50. [Online]. Available from: http://www.optometry.co.uk/uploads/articles/cet-2014/cet1_february_14_phil_gilbert.pdf [Accessed 22-08-2014].
Gillham, B. (2000) *Developing a Questionnaire.* London: Continuum.
Gilmartin, B. (2004) Myopia: precedents for research in the twenty-first century. *Clinical and Experimental Ophthalmology*, 32, (3) 305-324.
Gosling, S.D., Vazire, S., Srivastava, S. and John, O.P. (2004) Should we trust web-based studies? A comparative analysis of six preconceptions about internet questionnaires. *American Psychologist.*, 59, (2) 93-104.
Great Britain. Parliament. House of Commons (1974) *Health and Safety at Work Act.*
Griess, G.A. and Blankenstein, M.F. (1981) Additivity and repair of actinic retinal lesions. *Investigative Ophthalmology and Visual Science*, 20, (6) 803-807.
Guanyi Aero [no date] *Sun protection products*. [Online] from Guanyi Aero: http://www.guanyiaero.com/guanyiaero_info_en.php?dii=724 [Accessed 05-08-2014].
Guyatt, G. (1998) *Physics of the Environment and Climate.* Chichester: John Wiley.
Ham, W. J., Jr. and Mueller, H. A. (1989) The Photopathology and Nature of the Blue Light and Near-UV Retinal Lesions Produecd by Lasers and Other Optical Sources, In Wolbarsht, M.L. (ed.) *Laser Applications in Medicine and Biology.* New York: Plenum Publishing Corp., pp. 191-246.
Ham, W.T., Jr., Mueller, H.A. and Sliney, D.H. (1976) Retinal sensitivity to damage from short wavelength light. *Nature*, 260, (5547) 153-155.
Ham, W.T., Jr., Ruffolo, J.J., Jr., Mueller, H.A. and Guerry, D., III (1980) The nature of retinal radiation damage: dependence on wavelength, power level and exposure time. *Vision Research*, 20, (12) 1105-1111.
Hammer, G.P., Blettner, M. and Zeeb, H. (2009) Epidemiological studies of cancer in aircrew. *Radiation Protection Dosimetry*, 136, (4) 232-239.
Health and Safety Executive (1999) *Health and Safety at Work Regulations*.
Health and Safety Executive. (2010) *Guidance for employers on the control of Artificial Optical Radiation at Work Regulations (AOR) 2010*. [Online] from Health and Safety Executive: http://www.hse.gov.uk/radiation/nonionising/employers-aor.pdf [Accessed 05-09-2014].

Heckathorn, D.D. (1997) Respondent-Driven Sampling: A new approach to the study of hidden populations. *Social Problems*, 44, (2) 174-199.

Hietanen, M. (1991) Ocular exposure to solar ultraviolet and visible radiation at high latitudes. *Scandinavian Journal of Work, Environment and Health*, 17, (6) 398-403.

Honsberg, C. and Bowden, S. [no date] *Azimuth Angle*. [Online] from pveducation: http://pveducation.org/pvcdrom/properties-of-sunlight/azimuth-angle [Accessed 02-09-2014].

Honsberg, C. and Bowden, S. [no date] *Sun Position Calculator*. [Online] from pveducation: http://pveducation.org/pvcdrom/properties-of-sunlight/sun-position-calculator [Accessed 09-09-2014].

Information Commisioner's Office (2010) *Data Protection Act - Legal Guidance*.

International Civil Aviation Organisation (2012) *Manual of Civil Aviation Medicine*. 3rd ed. Doc 8984 AN/895.

International Commission on Non-ionising Radiation Protection (2004) ICNIRP guidelines on limits of exposure to ultraviolet radiation of wavelengths between 180nm and 400nm (incoherent optical radiation). *Health Physics*, 87, (2) 171-186.

International Commission on Non-ionising Radiation Protection (2010) ICNIRP statement on protection of workers against UV radiation. *Health Physics*, 99, (1) 66-87.

International Commission on Non-ionising Radiation Protection (2013) ICNIRP guidelines on limits of exposure to incoherent visible and infrared radiation. *Health Physics*, 105, (1) 74-96.

International Non-ionizing Radiation Committee of the International Radiation Protection Association (1989) Proposed change to the IRPA 1985 guidelines on limits of exposure to ultraviolet radiation. *Health Physics*, 56, (6) 971-972.

International Standard. ISO 12311 (2013) *Personal protective equipment - Test methods for sunglasses and related eyewear*. Switzerland: ISO.

International Standard. ISO 12312-1 (2013) *Eye and face protection - Sunglasses and related eyewear - Part 1: Sunglasses for general use*. Switzerland: ISO.

International Standard ISO 21348 (2007) *Space environment (natural and artificial) - Process for determining solar irradiances*. Switzerland: ISO.

Jalie M. (2005) Materials for spectacle lenses: optical and mechanical performance. *Optometry Today*, 28/01/2005, pp26-32. [Online] from: http://www.optometry.co.uk/uploads/articles/a69faccac732d6364b51d2081564df74_jalie20050128.pdf [Accessed 04-09-2014].

Joint Aviation Authorities (2006) *JAR-FCL 3: Flight crew licencing (medical).* ammendment 5.

Kagami, S., Bradshaw, S.E., Fukumoto, M. and Tsukui, I. (2009) Cataracts in airline pilots: prevalence and aeromedical considerations in Japan. *Aviation, Space and Environmental Medicine*, 80, (9) 811-814.
Kanski J.J. (2007) *Clinical Ophthalmology: a systematic approach*. Edinburgh: Elsevier Butterworth-Heinemann.
Kaya, S., Weigert, G., Pemp, B., Sacu, S., Werkmeister, R.M., Dragostinoff, N., Garhofer, G., Schmidt-Erfurth, U. and Schmetterer, L. (2012) Comparison of macular pigment in patients with age-related macular degeneration and healthy control subjects - a study using spectral fundus reflectance. *Acta Ophthalmologica*, 90, (5) e399-e403.
Kelly, S.P., Thornton, J., Edwards, R., Sahu, A. and Harrison, R. (2005) Smoking and cataract: review of causal association. *Journal of Cataract and Refractive Surgery*, 31, (12) 2395-2404.
Khazova, M. and O'Hagan, J.B. 2008. Optical radiation emissions from compact fluorescent lamps. *Radiation Protection Dosimetry*, 131, (4) 521-525.
Kimlin, M.G., Parisi, A.V., Sabburg, J. and Downs, N.J. (2002) Understanding the UVA environment at a sub-tropical site and its consequent impact on human UVA exposure. *Photochemical and Photobiological Sciences*, 1, (7) 478-482.
Kligman, L.H. and Gebre, M. (1991) Biochemical changes in hairless mouse skin collagen after chronic exposure to ultraviolet-A radiation. *Photochemistry and Photobiology*, 54, (2) 233-237.
Kohn, G. M. & Harper, M. D. [no date] *UV-B exposure in a commercial airline operation*. Unpublished Work.
Kronschlager, M., Lofgren, S., Yu, Z., Talebizadeh, N., Varma, S.D. and Soderberg, P. (2013) Caffeine eye drops protect against UV-B cataract. *Experimental Eye Research*, 113, 26-31.
Krzyscin, J.W., Jaroslawski, J. and Sobolewski, P.S. (2003) Effects of clouds on the surface erythemal UV-B irradiance at northern midlatitudes: estimation from the observations taken at Belsk, Poland (1999–2001). *Journal of Atmospheric and Solar-Terrestrial Physics*, 65, (4) 457-467.
Kuchinke, C. and Nunez, M. (1999) Cloud transmission estimates of UV-B erythemal irradiance. *Theoretical and Applied Climatology*, 63, (3-4) 149-161.
Kvale, S. (1996) *InterViews: An introduction to qualititative research interviewing* Thousand Oaks, CA: Sage Publications.
Kwok, L.S., Kuznetsov, V.A., Ho, A. and Coroneo, M.T. (2003) Prevention of the adverse photic effects of peripheral light-focusing using UV-blocking contact lenses. *Investigative Ophthalmology and Visual Science*, 44, (4) 1501-1507.

Kwok, L.S., Daszynski, D.C., Kuznetsov, V.A., Pham, T., Ho, A., and Coroneo, M.T. (2004) Peripheral light focusing as a potential mechanism for phakic dysphotopsia and lens phototoxicity. *Ophthalmic and Physiological Optics*, 24, (2) 119-129.

Lam H. [no date] *Performance of UV-Vis Spectrophotometers*. [Online] from: http://www.cvg.ca/images/Performance_UV_Vis.pdf [Accessed 04-09-2014].

Lavker, R. and Kaidbey, K. (1997) The spectral dependence for UVA-induced cumulative damage in human skin. *Journal of Investigative Dermatology*, 108, (1) 17-21.

Lavker, R.M., Gerberick, G.F., Veres, D., Irwin, C.J. and Kaidbey, K.H. (1995) Cumulative effects from repeated exposures to suberythemal doses of UVB and UVA in human skin. *Journal of the American Academy of Dermatology*, 32, (1) 53-62.

Loane, E., Kelliher, C., Beatty, S. and Nolan, J.M. (2008) The rationale and evidence base for a protective role of macular pigment in age-related maculopathy. *British Journal of Ophthalmology*, 92, (9) 1163-1168.

Lockley, S.W., Brainard, G.C. and Czeisler, C.A. (2003) High sensitivity of the human circadian melatonin rhythm to resetting by short wavelength light. *Journal of Clinical Endocrinology and Metabolism*, 88, (9) 4502-4505.

Loughman J, Davison, P., Nolan, J. M., Akkali, M. C. and Beatty, S. (2010) Macular pigment and its contribution to visual performance and experience. *Journal of Optometry,* 3[2], 73-89.

Loughman, J., Akkali, M.C., Beatty, S., Scanlon, G., Davison, P.A., O'Dwyer, V., Cantwell, T., Major, P., Stack, J. and Nolan, J.M. (2010) The relationship between macular pigment and visual performance. *Vision Research*, 50, (13) 1249-1256.

Lowe, N.J., Meyers, D.P., Wieder, J.M., Luftman, D., Borget, T., Lehman, M.D., Johnson, A.W. and Scott, I.R. (1995) Low doses of repetitive ultraviolet A induce morphologic changes in human skin. *Journal of Investigative Dermatology*, 105, (6) 739-743.

Lubin, D. and Frederick, J.E. (1991) The ultraviolet radiation environment of the Antarctic Peninsula: The roles of ozone and cloud cover. *Journal of Applied Meteorology.*, 30, 478-493.

Lund, D.J., Stuck, B.E. and Edsall, P. (2006) Retinal injury thresholds for blue wavelength lasers. *Health Physics*, 90, (5) 477-484.

Madronich, S. (1993) The atmosphere and UV-B radiation at ground level, in Young, A.R., Bjoern, L.O., Moan, J. and Nultsch, W. (Eds.) *Environmental UV Photobiology*, New York: Plenum Press. pp1-39.

Madronich, S., McKenzie, R.L., Bjorn, L.O. and Caldwell, M.M. (1998) Changes in biologically active ultraviolet radiation reaching the Earth's surface. *Journal of Photochemistry and Photobiology,* B:Biology, 46, (1-3) 5-19.

Mainster, M.A. and Turner, P.L. (2010) Blue-blocking IOLs decrease photoreception without providing significant photoprotection. *Survey of Ophthalmology*, 55, (3) 272-289.

Mainster, M.A. and Turner, P.L. (2012) Glare's causes, consequences, and clinical challenges after a century of ophthalmic study. *American Journal of Ophthalmology*, 153, (4) 587-593.

McCarty, C.A., Nanjan, M.B. and Taylor, H.R. (2000) Attributable risk estimates for cataract to prioritize medical and public health action. *Investigative Ophthalmology and Visual Science*, 41, (12) 3720-3725.

McCarty, C.A. and Taylor, H.R. (2002) A review of the epidemiologic evidence linking ultraviolet radiation and cataracts. *Developments in Ophthalmology*, 35, 21-31.

McCormick, P.G. and Suehrcke, H. (1990) Cloud-reflected radiation. *Nature*, 345, 773.

McKenzie, R.L., Kotkamp, M., Seckmeyer, G., Erb, R., Roy, C.R., Gies, H.P. and Toomey, S.J. (1993) First southern hemisphere intercomparison of measured solar UV spectra. *Geophysical Research Letters*, 20, (20) 2223-2226.

McKenzie, R.L., Aucamp, P.J., Bais, A.F., Bjorn, L.O., Ilyas, M. and Madronich, S. (2011) Ozone depletion and climate change: impacts on UV radiation. *Photochemical and Photobiological Sciences*, 10, (2) 182-198.

Meinel A.B. and Meinel M.P. (1976) *Applied Solar Energy: An Introduction.* Reading, MA: Addison-Wesley.

Mellerio, J. (1994) Light effects on the retina, in Albert, D.M. and Jokobiec, F.A. (eds.) *Principles and Practice of Ophthalmology*, Philadelphia: W B Saunders Co. pp.1-23.

Millidot M. (1990) *Dictionary of Optometry*. 2nd ed. London: Butterworths.

Mitchell, D. and Fernandez, A. (2012) The photobiology of melanocytes modulates the impact of UVA on sunlight-induced melanoma. *Photochemical and Photobiological Sciences*, 11, (1) 69-73.

Moehrle, M., Dennenmoser, B. and Garbe, C. (2003) Continuous long-term monitoring of UV radiation in professional mountain guides reveals extremely high exposure. *International Journal of Cancer*, 103, (6) 775-778.

Moreno, J.C., Serrano, M.A., Canada, J., Gurrea, G. and Utrillas, M.P. (2014) Effect of the relative optical air mass and the clearness index on solar erythemal UV irradiance. *Journal of Photochemistry and Photobiology,* B:Biology, 138, 92-98.

Murphy, K., Casey, D., Devane, D., Meskell, P., Begley, C., Higgins, A., Elliot, N. and Lalor, J. (2014) Reflections on the added value of using mixed methods in the SCAPE study. *Nurse Researcher*, 21, (4) 13-19.

mypilotstore.com [no date] *Moveable sun visor*. [Online] from mypilotstore: http://www.mypilotstore.com/mypilotstore/sep/7180 [Accessed 04-09-2014].

Nakagawara, V.B., Wood, K.J., and Montgomery, R.W. (2002) The use of contact lenses by U.S. civilian pilots. *Optometry*, 73, (11) 674-684.

Nakagawara, V.B., Montgomery, R.W. and Marshall, W.J. (2007) *Optical Radiation Transmittance of Aircraft Windscreens and Pilot Vision.* Oklahoma City, OK: Federal Aviation Administration Civil Aerospace Medical Inst.

NASA (2008) *Solar cycle 24 begins*. [Online] from National Aeronautics and Space Administration: http://science.nasa.gov/science-news/science-at-nasa/2008/10jan_solarcycle24/ [Accessed 22-08-2014].

Nicholas, J.S., Butler, G.C., Lackland, D.T., Tessier, G.S., Mohr, L.C., Jr., and Hoel, D.G. (2001) Health among commercial airline pilots. *Aviation, Space and Environmental Medicine*, 72, (9) 821-826.

Nikon (2012) *Seecoat Blue UV: Blue light control coating with UV protection*. [Online] from Nikon: http://www.nikonlenswear.co.uk/products/treatments/seecoat-blue [Accessed 05-09-2014].

Noell, W.K., Walker, V.S., Kang, B.S. and Berman, S. (1966) Retinal damage by light in rats. *Investigative Ophthalmology and Visual Science*, 5, (5) 450-473.

Nolan, J.M., Loughman, J., Akkali, M.C., Stack, J., Scanlon, G., Davison, P. and Beatty, S. (2011) The impact of macular pigment augmentation on visual performance in normal subjects: COMPASS. *Vision Research*, 51, (5) 459-469.

Ocean Optics [no date, a] *CC-3 Cosine Corrected Probes*. [Online]. Available from: Ocean Optics online. http://oceanoptics.com/product/cosine-correctors/ [Accessed 9 September 2014].

Ocean Optics [no date, b] *LS-1-CAL Series Calibration Light Sources – Installation and Operation Instructions*. [Online] from Ocean Optics: http://oceanoptics.com/support/technical-documents/ [Accessed 9 September 2014].

Ocean Optics [no date, c] *74-UV, 74-VIS Collimating Lenses*. [Online] from Ocean Optics: http://oceanoptics.com/product/collimating-lens-74-series/ [Accessed 9 September 2014].

Ocean Optics [no date, d] *Grating Efficiency Curves: HC1 Composite Grating*. [Online] from Ocean Optics: http://oceanoptics.com/product-details/hr-custom-configured-gratings-wavelength-range/ [Accessed 9 September 2014].

Ocean Optics [no date, e] *HR4000 Data Sheet*. [Online] from Ocean Optics: http://oceanoptics.com/support/technical-documents/ [Accessed 9 September 2014].

Ocean Optics (2007) *SpectraSuite Spectrometer Operating Software – Installation and Operation Manual.* [Online] from Ocean Optics: http://oceanoptics.com/support/technical-documents/ [Accessed 9 September 2014].

Ocean Optics (2008a) *HR4000 and HR4000CG-UV-NIR Series High Resolution Fiber Optic Spectrometers HR4000 / HR4000CG-UV-NIR Installation and Operation Manual.* [Online] from Ocean Optics: http://oceanoptics.com/support/technical-documents/ [Accessed 9 September 2014].

Ocean Optics (2008b) *Halogen Light Source with Attenuator and TTL Shutter HL-2000-HFSA/HL-2000-HFSA-LL/HL-2000-HFSA-HP Installation and Operation Manual*. [Online] from Ocean Optics: http://oceanoptics.com/support/technical-documents/ [Accessed 9 September 2014].

Oppenheim A.N. (1992) *Questionnaire design, interviewing and attitude measurement.* London: Printer pub Ltd.

Organisciak, D.T. and Vaughan, D.K. (2010) Retinal light damage: mechanisms and protection. *Progress in Retinal and Eye Research*, 29, (2) 113-134.

Pang, J., Seko, Y., Tokoro, T., Ichinose, S. and Yamamoto, H. (1998) Observation of ultrastructural changes in cultured retinal pigment epithelium following exposure to blue light. *Graefe's Archive for Clinical and Experimental Ophthalmology*, 236, (9) 696-701.

Parisi, A.V. and Kimlin, M.G. (2000) Estimate of Annual Ultraviolet-A Exposures in Cars in Australia. *Radiation Protection Dosimetry*, 90, (4) 409-416.

Parisi, A.V., Wong, J.C., Kimlin, M.G., Turnbull, D. and Lester, R. (2001) Comparison between seasons of the ultraviolet environment in the shade of trees in Australia. *Photodermatology Photoimmunology and Photomedicine*, 17, (2) 55-59.

Parisi, A.V., Sabburg, J. and Kimlin, M.G. (2004) *Scattered and filtered solar UV measurements.* Dordrecht: Kluwer Acedemic Publishers.

Penn, J.S. and Williams, T.P. (1986) Photostasis: regulation of daily photon-catch by rat retinas in response to various cyclic illuminances. *Experimental Eye Research*, 43, (6) 915-928.

Pitts, D.G. (1990) Ultraviolet-absorbing spectacle lenses, contact lenses, and intraocular lenses. *Optometry and Vision Science*, 67, (6) 435-440.

PPG aerospace Transparencies (2009) *Transparency Bulletin: Alteos interactive window systems*. (Summer 2009) [Online] from PPG aerospace: http://www.ppg.com/coatings/aerospace/transparencies1/alteos_comm_tb_09.pdf [Accessed 09-09-2014].

Price, L.L., Hooke, R.J. and Khazova, M. (2014) Effects of ambient temperature on the performance of CCD array spectroradiometers and practical implications for field measurements. *Journal of Radiological Protection*, 34, (3) 655-673.

Quesada J. & Senar J. (2006) Comparing plumage colour measurements obtained directly from live birds and from collected feathers: the case of the great tit Parus major. *Journal of Avian Biology*, 37, (6) 609-616.

Rafnsson, V., Olafsdottir, E., Hrafnkelsson, J., Sasaki, H., Arnarsson, A. and Jonasson, F. (2005) Cosmic radiation increases the risk of nuclear cataract in airline pilots: a population-based case-control study. *Archives of Ophthalmology*, 123, (8) 1102-1105.

Rebok, G.W., Qiang, Y., Baker, S.P. and Li, G. (2007) Age-related vision problems in commuter and air taxi pilots: a study of 3019 pilots, 1987-1997. *Aviation, Space and Environmental Medicine*, 78, (7) 706-711.

Ridout Plastics [no date] *ePlastics Plexiglass acrylic sheet - UV filtering*. [Online] from Ridout Plastics Co. Inc: http://www.eplastics.com/Plexiglass_Acrylic_Sheet_UV_Filter [Accessed 09-09-2014].

Ronto, G., Gaspar, S. and Berces, A. (1992) Phage T7 in biological UV dose measurement. *Journal of Photochemistry and Photobiology,* B:Biology, 12, (3) 285-294.

Roscoe, A.H. and Diffey, B.L. (1994) A preliminary study of blue light on an aircraft flight deck. *Health Physics*, 66, (5) 565-567.

Rosenthal, F.S., Bakalian, A.E. and Taylor, H.R. (1986) The effect of prescription eyewear on ocular exposure to ultraviolet radiation. *American Journal of Public Health*, 76, (10) 1216-1220.

Rosenthal, F.S., Bakalian, A.E., Lou, C.Q. and Taylor, H.R. (1988) The effect of sunglasses on ocular exposure to ultraviolet radiation. *American Journal of Public Health*, 78, (1) 72-74.

Ryu, Y., Lee TS, Lubguban J.A., White H.W., Kim BJ., Park YS., and Youn CJ. (2006) Next generation of oxide photonic devices: ZnO-based ultraviolet light emiiting diodes. *Applied Physics Letters,* 88[24], 241108.

Sabburg, J. and Wong, J. (2000) The effect of clouds on enhancing UVB irradiance at the earth's surface: a one year study. *Geophysical Research Letters*, 27, (20) 3337-3340.
Sabburg, J., Parisi, A.V. and Wong, J. (2001) Effect of cloud on UVA and exposure to humans. *Photochemistry and Photobiology*, 74, (3) 412-416.
Sanlorenzo, M., Wehner, M.R., Linos, E., Kornak, J., Kainz, W., Posch, C., Vujic, I., Johnston, K., Gho, D., Monico, G., McGrath, J.T., Osella-Abate, S., Quaglino, P., Cleaver, J.E. and Ortiz-Urda, S. (2014) The Risk of Melanoma in Airline Pilots and Cabin Crew: A Meta-analysis. *JAMA Dermatology* pp.E1-E7. [Online]. DOI:10.1001/jamadermatol.2014.1077 [Accessed 05-09-2014].
Sasaki, H., Sakamoto, Y., Schnider, C., Fujita, N., Hatsusaka, N., Sliney, D.H. and Sasaki, K. (2011) UV-B exposure to the eye depending on solar altitude. *Eye and Contact Lens*, 37, (4) 191-195.
Seckmeyer, G. and Bernhard, G. (1993) Cosine error correction of spectral UV-irradiances, in: *Atmospheric Radiation*. Proc. SPIE. Bellingham: Washington, vol.2049, pp.140-151.
Serrano, M.A., Canada, J. and Moreno, J.C. (2013) Solar UV exposure in construction workers in Valencia, Spain. *Journal of Exposure Science and Environmental Epidemiology*, 23, (5) 525-530.
Serrano, M.A., Canada, J., Moreno, J.C. and Gurrea, G. (2014) Personal UV exposure for different outdoor sports. *Photochemical and Photobiological Sciences*, 13, (4) 671-679.
Sliney, D.H. (2002) How light reaches the eye and its components. *International Journal of Toxicology*, 21, (6) 501-509.
Solanki V, Eperiesi F. and Bartlett H. (2007) Ocular Nutrition: Part 2 The blue-light hazard. *Optometry Today*, 47, (2) pp30-38 [Online]. Available from: http://www.optometry.co.uk/uploads/articles/C-6992.pdf [Accessed 04-09-2014]
Spencer J. (2003a) A Good Pair of Shades. *The Aviation Consumer,* 33[4], 8-32.
Spencer J. (2003b) Sunglasses for Pilots. *The Aviation Consumer*, 33[6], 14-19.
Stringham, J.M., Garcia, P.V., Smith, P.A., McLin, L.N. and Foutch, B.K. (2011) Macular pigment and visual performance in glare: benefits for photostress recovery, disability glare, and visual discomfort. *Investigative Ophthalmology and Visual Science*, 52, (10) 7406-7415.
Stringham, J.M. and Hammond, B.R., Jr. (2007) The glare hypothesis of macular pigment function. *Optometry and Vision Science*, 84, (9) 859-864.
Stringham, J.M. and Hammond, B.R., Jr. (2008) Macular pigment and visual performance under glare conditions. *Optometry and Vision Science*, 85, (2) 82-88.

SunEarthTools.com [no date] *Distance and bearing calculator.* [Online] from sunearthtools.com: http://www.sunearthtools.com/tools/distance.php [Accessed 09-09-2014].
Tang, X., Madronich, S., Wallington, T. and Calamari, D. (1998) Changes in tropospheric composition and air quality. *Journal of Photochemistry and Photobiology,* B:Biology, 46, (1-3) 83-95.
Tate, T.J., Diffey , B.L. and Davis, A. (1980) An ultraviolet radiation dosimeter based on the photosensitising drug, Nalidixic Acid. *Photochemistry and Photobiology*, 31, (1) 27-30.
Taylor, H.R., West, S., Munoz, B., Rosenthal, F.S., Bressler, S.B. and Bressler, N.M. (1992) The long-term effects of visible light on the eye. *Archives of Ophthalmology*, 110, (1) 99-104.
Thieden, E. (2008) Sun exposure behaviour among subgroups of the Danish population. Based on personal electronic UVR dosimetry and corresponding exposure diaries. *Danish Medical Bulletin*, 55, (1) 47-68.
Thiel, S., Steiner, K. and Seidlitz, H.K. (1997) Modification of global erythemally effective irradiance by clouds. *Photochemistry and Photobiology*, 65, (6) 969-973.
Transair flight equipment [no date] *Slap-on sunvisor*. [Online] from Transair: http://www.transair.co.uk/sp+Cockpit-Items-Slap-On-Sun-Visor+3495 Accessed [04-09-2014].
Transitions Optical (2013) *Transitions XTRActive lenses*. [Online] from Transitions Optical Inc: http://www.transitions.com/en-gb/transitions-every-day/the-technology/photochromic-technology/ [Accessed 05-09-2014].
Turnbull, D.J. and Schouten, P.W. (2008) Utilising polyphenylene for high exposure solar UVA dosimetry. *Atmospheric Chemistry and Physics*, 8, 2759-2762.
Vitale, S., Sperduto, R.D. and Ferris, F.L., III. (2009). Increased prevalence of myopia in the United States between 1971-1972 and 1999-2004. *Archives of Ophthalmology*, 127, (12) 1632-1639.
Voke, J. (1999) Radiation effects on the eye - Ocular effects of ultraviolet radiation. *Optometry Today*, 39, (15) pp.37-40 [Online]. Available from: http://www.optometry.co.uk/uploads/articles/3e8d525e226106ac5cf89c9005c215d2_Voke19990716.pdf [Accessed 04-09-2014].
Vos, J.J. (2003) On the cause of disability glare and its dependence on glare angle, age and ocular pigmentation. *Clinical and Experimental Optometry*, 86, (6) 363-370.
Wang, J.J., Jakobsen, K., Smith, W. and Mitchell, P. (2003) Five-year incidence of age-related maculopathy in relation to iris, skin or hair colour, and skin sun

sensitivity: the Blue Mountains Eye Study. *Clinical and Experiment.Ophthalmology*, 31, (4) 317-321.
Wang, S.Q., Setlow, R., Berwick, M., Polsky, D., Marghoob, A.A., Kopf, A.W. and Bart, R.S. (2001) Ultraviolet A and melanoma: a review. *Journal of the American Academy of Dermatology*, 44, (5) 837-846.
Weihs, P., Scheifinger, H., Rengarajan, G. and Simic, S. (2000) Effect of topography on average surface albedo in the ultraviolet wavelength range. *Applied Optics*, 39, (21) 3592-3603.
Weihs, P., Webb, A.R., Hutchinson, S.J. and Middleton, G.W. (2000) Measurements of the diffuse UV sky radiance during broken cloud conditions. *Journal of Geophysical Research*, 105, (D4) 4937-4944.
Wen, G. and Frederick, J.E. (1995) The effects of horizontally extended clouds on backscattered ultraviolet sunlight. *Journal of Geophysical Research*, 100, (D8) 16387-16393.
West, E.S. and Schein, O.D. (2005) Sunlight and age-related macular degeneration. *International Ophthalmology Clinics*, 45, (1) 41-47.
Wilkinson P. (2006) Coatings and tints: Product availability and choice. *Optometry Today,* 46[4], pp.23-29. [Online] from: http://www.optometry.co.uk/uploads/articles/3f6c89a1e65c45f7596df5a1ab6dc80b_Wilkinson_payl23206.pdf [Accessed: 04-09/2014].
Winn, B., Whitaker, D., Elliott, D.B. and Phillips, N.J. (1994) Factors affecting light-adapted pupil size in normal human subjects. *Investigative Ophthalmology and Visual Science*, 35, (3) 1132-1137.
Wolffsohn, J.S. (2013) The benefits of UV-blocking contact lenses. *Optometry in Practice*, 14, (2) 61-72.
Wong, C.F., Fleming, R.A., Carter, S.J., Ring, I.T. and Vishvakarman, D. (1992) Measurement of human exposure to ultraviolet-B solar radiation using a CR-39 dosimeter. *Health Physics*, 63, (4) 457-461.
Wong, C.F., Toomey, S., Fleming, R.A. and Thomas, B.W. (1995) UV-B radiometry and dosimetry for solar measurements. *Health Physics*, 68, (2) 175-184.
Wong, C.F. and Parisi, A.V. (1996) Measurement of UVA exposure to solar radiation. *Photochemistry and Photobiology*, 63, (6) 807-810.
World Health Organisation (1993) *The effects of Solar UV Radiation on the eye*. WHO/PBL/EHG/94.1.
World Health Organisation (2002) *Global Solar UV Index: A practical guide.* WHO/SDE/OEH/02.2.

World Health Organisation (2006) *Solar Ultraviolet Radiation: Global burden of disease from solar ultraviolet radiation.* Environmental Burden of Disease Series, No.13. Geneva: WHO.

Wright, K.B. (2005) Researching Internet-Based Populations: Advantages and Disadvantages of Online Survey Research, Online Questionnaire Authoring Software Packages, and Web Survey Services. *Journal of Computer-Mediated Communication,*10, (3). [Online]. Available from: http://onlinelibrary.wiley.com/doi/10.1111/j.1083-6101.2005.tb00259.x/full [Accessed 09-09-2014].

Wu, J., Seregard, S. and Algvere, P.V. (2006) Photochemical damage of the retina. *Survey of Ophthalmology*, 51, (5) 461-481.

Yang, H. and Afshari, N.A. (2014) The yellow intraocular lens and the natural ageing lens. *Current Opinion in Ophthalmology*, 25, (1) 40-43.

Young, R.W. (1988) Solar radiation and age-related macular degeneration. *Survey of Ophthalmology*, 32, (4) 252-269.

Young, R.W. (1994) The family of sunlight-related eye diseases. *Optometry and Vision Science*, 71, (2) 125-144.

Youssef, P.N., Sheibani, N. and Albert, D.M. (2011) Retinal light toxicity. *Eye (London)*, 25, (1) 1-14.

Appendices

Appendix A: Chorley, A. et al, (2011) Civilian pilot exposure to ultraviolet and blue light and pilot use of sunglasses.

Civilian Pilot Exposure to Ultraviolet and Blue Light and Pilot Use of Sunglasses

Adrian C. Chorley, Bruce J. W. Evans, and Martin J. Benwell

Chorley AC, Evans BJW, Benwell MJ. ***Civilian pilot exposure to ultraviolet and blue light and pilot use of sunglasses.*** **Aviat Space Environ Med 2011; 82:895–900.**

Population and animal studies indicate that long-term exposure to short-wavelength visible light and ultraviolet (UV) radiation causes increased risk of certain ocular pathologies such as cataracts and maculopathy. The potential risk to flight crew is unknown. The UK Civil Aviation Authority (CAA) has issued guidance to pilots regarding sunglass selection; however, it is not known if this guidance is appropriate given pilots' unique occupational environment. A search and appraisal of the relevant literature was conducted which showed that within the airline pilot population, there is limited evidence of a higher prevalence of cataracts. There are no data of other known UV-related ocular pathology. There is some evidence of higher prevalence of skin melanomas. Studies measuring cockpit UV radiation levels are limited and leave unanswered questions regarding airline pilot exposure. Data from optical transmission of cockpit windshields demonstrates the UV blocking properties at sea level. No studies have addressed the occupational use of sunglasses in airline pilots. Although it is likely that an aircraft windshield effectively blocks UV-B, the intensity of UV-A and short wavelength blue light present within the cockpit at altitude is unknown. Pilots may be exposed to solar radiation for periods of many hours during flight where UV radiation is known to be significantly greater. Aircraft windshields should have a standard for optical transmission, particularly of short-wavelength radiation. Clear, untinted prescription glasses will offer some degree of UV protection; however, sunglasses will offer superior protection. Any sunglasses used should conform to a national standard.

Keywords: airline pilots, UV, blue light hazard, ocular exposure, sunglasses.

AIRLINE PILOTS ARE exposed to large variations in light levels within the cockpit environment. Factors influencing pilot exposure to solar radiation include azimuth of the sun, time of day and year, light reflection from surfaces such as snow or cloud top, filtering effect of the ozone layer, the aircraft's track, attitude, and altitude, transmission properties of the cockpit windshield, and the use of protection (sunglasses) by airline pilots. It is feasible that daytime long-haul flights expose airline pilots to high light levels for prolonged periods of time, particularly when 'chasing the sun' flying east to west during daylight hours.

Ultraviolet (UV) radiation is defined as the waveband 100-400 nm. It is generally subdivided into UV-A (315-400 nm), UV-B (280-315 nm), and UV-C (100-280 nm) (20). The main source of UV radiation is from the sun. The Earth's atmosphere, including the ozone layer, is responsible for filtering the UV-C and most of the UV-B radiation. UV radiation increases by 10–12% every 1000 m in altitude (3,45). This translates to a 170–290% increase in UV between sea level and a cruise altitude of 35,000 ft (10,668 m). This would be expected to increase further where reflection from cloud top or snow is present (45). Blue light falls within the 400-500 nm range.

A photon is the basic unit of electromagnetic radiation. The amount of energy of a photon is inversely proportional to the wavelength (λ) of the radiation, as described by the Planck-Einstein equation $E = hc/\lambda$. This means that radiation of short wavelength (UV and blue light) carries more energy and is more damaging to human tissue than that of longer wavelength (for example green and red) light.

The areas of the body at most risk of excessive exposure to UV are the eyes and the skin. The National Radiological Protection Board (31) suggests that approximately 1 million workers are exposed to high levels of optical radiation from the sun. It is recognized that many of these individuals work outside and are involved in manual labor. Less than 1% of UV radiation below 340 nm reaches the retina; the remainder is absorbed by the cornea and lens. This means that most UV is absorbed by the anterior structures of the eye, the cornea and lens, which are, therefore, most at risk of damage. Although only 10% of short wavelength blue light reaches the retina (42), there is evidence to suggest that long-term exposure is sufficient to disrupt its structure.

It is known that intense exposure to UV can disturb the cornea, which absorbs all UV below 300 nm and 40% of UV at 320 nm (44). This can cause an acutely painful inflammation of the cornea, known as photokeratitis. This is not relevant to aviation since UV levels in this band of wavelengths are not sufficiently intense in aircraft cockpits to invoke this response, which more commonly occurs following insufficient eye protection during electric arc welding. A large body of evidence supports the proposition that long-term exposure to UV is a risk

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factor for cataracts (9,14,26). UV-induced cataracts are likely to arise through oxidative stress causing an increase in reactive oxygen species (chemically reactive molecules which can, in turn, cause damage to the lens DNA and cross-linking of proteins) (5). There is a higher risk of cortical cataract with UV-B exposure consistent through different study designs, different populations, and varying levels of other known risk factors (27). There is only weak evidence for any association with other ocular surface conditions (44).

A multicenter study by Brilliant et al. (4) assessed the presence of cataract in 30,565 life-long residents of Nepal and found a positive association between cataract and increased sunlight exposure. Surprisingly, there was a negative correlation of similar magnitude between altitude and cataract prevalence, which the authors attribute to tall neighboring mountains blocking the sun. The authors did not consider other potentially confounding factors, such as diet.

Increasing evidence (38,43,46) supports an association between solar radiation exposure and the risk of age-related macula degeneration (AMD). This condition involves degeneration of the photoreceptors in the macula area of the retina (25) and is the most common cause of irreversible visual loss in the developed world in individuals over 50 yr of age (23). Taylor et al. (41) found that, in a population of watermen, those with advanced dry AMD had significantly higher exposure to predicted blue or visible light, but no difference with regard to UV-A or UV-B exposure. Deep blue light has been described as 50-80 times more efficient at causing photoreceptor damage than green light (34). This 'blue light hazard' has an excitation peak around 440 nm (due to the photobiological action spectrum). Although some of the evidence is limited by the use of animal models, there is persuasive evidence that long-term exposure to high levels of solar radiation is a factor in photoreceptor damage (1) and a plausible mechanism for the damage has been identified (18,32,43).

There is increased risk of late AMD following cataract removal and lens implant (1) as the crystalline lens absorbs an increasing proportion of shorter wavelength visible light during cataract development. UV and blue light hazard blocking filters have been shown to cause significantly less retinal damage in animal models. Intraocular lens implants with short wavelength filtering properties are being used increasingly. Additionally, it has been proposed that a sensitivity to glare and poor tanning ability increase AMD risk (12). Outdoor leisure time has been significantly associated with an increased risk of early AMD in later years (10).

Part of the UK Civil Aviation Authority's (CAA) remit covers flight crew health issues (8). The CAA has issued guidance to pilots on sunglass selection (7). This paper aims to address UV and short-wavelength visible electromagnetic radiation exposure in airline pilots, the prevalence of related ocular pathology within the pilot population, and the use of eye protection in the cockpit.

METHODS

A review of the English language literature was undertaken to identify relevant studies. All electronic searches were made through PubMed and Cochrane databases. In order to establish literature on optical transmission properties of cockpit windshields, additional electronic searches were conducted through the International Civil Aviation Organization, Federal Aviation Administration, Civil Aviation Authority, and 'Google Scholar' search engine.

To determine studies addressing the use of sunglasses in airline pilots, an additional search was made through 'Google Scholar' search engine to identify relevant journal articles. Searches were also made through aviation medicine books, the International Civil Aviation Organization, Federal Aviation Administration, and the Civil Aviation Authority. Relevant papers found referenced from the original shortlist or unpublished papers presented at scientific meetings were included. The final electronic search was conducted on 22 February 2011.

RESULTS

Two studies were identified regarding radiation levels within the cockpit. Diffey and Roscoe (15) measured ultraviolet radiation exposure during flight using a 'polysulphore film' badge worn by pilots on the epaulette nearest to the side window. Recordings were taken from the captain and first officer on 12 flights, including long- and short-haul on a wide variety of routes worldwide. The total exposure during flight was then measured from the badge, although no details of this process were available. Further measurements were taken with separate badges at ground level 'around noon' from an unshaded horizontal surface in five locations worldwide.

The sensitivity of the film was 'confined principally to wavelengths less than 320 nm'. No detail was given regarding the accuracy of measurement of the films, the range over which the films were sensitive, or the protocol used to activate and deactivate the badges. For calibration purposes, UV levels were also measured by the authors on one flight using a radiometer with a sensor with 'similar spectral sensitivity' to the badges, although these data were not given. The results showed that all badges worn during flight had minimal exposure to UV radiation and were significantly less than readings taken outside at ground level. Although no statistical analysis was carried out, values were small and projected annual doses fell within recommended annual exposure for indoor workers.

The second study by Roscoe and Diffey (36) was a preliminary study of levels of blue light within the cockpit. Measurements were taken using a radiometer sensitive to 370-520 nm during just one flight on a Boeing 767 from London to Spain. The authors state that 50–60% of blue light was transmitted through an airbus A320 windshield, although this differed from the aircraft type used in their study.

A series of readings were taken during climb, cruise, and descent with the sensor in various directions. Wide variances in readings were found depending on the direction of the sensor, but little effect was found with altitude. Results were within recommended 'threshold limit values' defined by the American Conference of Governmental Industrial Hygienists. However, these limits are based primarily upon the threshold irradiance levels to produce acute photokeratitis (44). No statistical analysis was carried out and it is not known if the results were clinically significant. The authors comment that ocular exposure in flight may be higher due to a slightly nose up aircraft attitude during cruise compared to a marginally stooped human posture on the ground.

Recommendations for sunglasses with less than 10% transmission of blue light were made. It was not clear how this was derived based upon the data. The authors acknowledge that this was a preliminary study, however, no further published work was found.

One study was identified regarding the optical transmission of cockpit windshields. Nakagawara et al. (29) measured the optical transmission properties of eight windshields used in a wide range of aircraft types, including Boeing and Airbus. Three radiometers were used to measure the transmission of the windshields for radiation in the wavelength range 270 to 780 nm in a laboratory setting. Baseline readings without the windshield in place were taken between each measurement. The authors measured two windscreens under laboratory and field conditions for validation purposes.

Six windshields (all from large commercial aircraft) were laminated glass, with the remaining two being of single-layer polycarbonate material (from smaller general aviation aircraft). The results showed that transmission was less than 1% through both glass and plastic windshields from 280 to 320 nm (UV-B). Transmission varied between 0.41% and 53.5% from 320 to 380 nm (UV-A) with the plastic material showing superior UV blocking. The study, therefore, showed a high percentage of UV-A radiation was transmitted through some cockpit windshields. It remains uncertain what the properties of windshield transmission are at altitude, where different temperatures and composition of incident radiation would be present.

Inquiries were made within the UK Civil Aviation Authority (Scurrah M., personal communication; 1 December 2009) and with aircraft windshield manufacturers (Goudie A., personal communication; 8 December 2009) regarding windshield properties. There were requirements for bird strike and other debris impact resistance, resistance to variations in temperature, and cyclic loading. The only optical transmission requirement found was for a minimum transmission of the total visible light. Cockpit windshields are assessed at periodic maintenance and replaced if delamination, abrasion, or heater element problems are detected. A number of factors may influence the optical transmission profile of a windshield. These include the type of windshield design (three-layer laminate glass being common in large commercial jet aircraft), type of glass used, the specific area of the windshield, the material used for the de-icing heater element, and the number of elements used. Although windshields are replaced periodically, it is not known whether age would affect the optical transmission.

Four studies were found investigating the presence of cataracts in airline pilots. No studies assessing the incidence of other UV-related conditions, including AMD in pilots, were found. Nicholas et al. (30) investigated self-reported disease rates among 6609 active and retired American and Canadian airline pilots from two airlines through questionnaires. Data collected included age, gender, race, start and end years for commercial flying, lifestyle questions, presence of cataract, and cancer and non-cancer disease endpoints. The authors used an estimated standardized incidence ratio, using the length of time as a commercial pilot, to compare their data with available data from the general U.S. population. It was acknowledged that this could induce error as self-reported data in the pilot group was compared to record-based data in the control group. Additionally, the study group would have had to be free from disease at their initial medical and may not be representative of the general population.

A significantly higher incidence of cataracts in the pilot population was found. It was unclear how the authors or subjects defined cataract or how the questionnaire was worded in order to collect these data. The type or grade of cataract present was also not known. The authors found a significantly higher rate of motor neuron disease, which they felt was due to inaccuracy of pilot reporting. This may raise some doubt over the accuracy of the other data.

Rebok et al. (35) studied a cohort of 3019 male pilots (ages 45-54 yr) retrospectively over a 10-yr period. Data were collected through the U.S. aviation medical records system. The research aim was to identify age-related visual problems. The study contained no control group and therefore no comparison could be made to the general population. The authors aimed to assess the risk of visual problems with flight experience and age through parametric modeling.

Data were collected on a wide range of ocular pathologies and grouped into broad categories. The most prevalent visual pathology was 'corneal problems'. No further details were given and it is unknown if any were attributable to UV exposure. Cataract was the third most common visual disorder. No details of type or grade of cataract were given. For analysis, all data were combined to give a relative risk of 'visual problems' with flight experience. With regard to the presence of UV-related pathology, one can only conclude that cataracts were present in some pilots.

Kagami et al. (22) conducted a retrospective cohort study over a 12-mo period to determine the prevalence of cataract in 3780 Japanese airline pilots. Medical records were examined by one of the authors for the presence of cataract. Those cases detected had further data collected, including age at diagnosis and aeromedical decision outcome. The cataract type was classified by the authors based upon the documented appearance on record. It is not clear if this diagnosis differed from that of the original examiner and no interobserver reliability measures were taken. Cataracts were documented as congenital or secondary/age-related.

The authors compared their results to a Japanese population study and concluded that the prevalence of cataracts in the pilot population was 'significantly lower' than the general population. It is not known how the data compare to a Caucasian pilot population. The most common age-related cataract detected was cortical followed by nuclear. No raw data were given and no statistical analysis was conducted. The authors question whether the pilot population is 'healthier' than the general population, but conclude that early cortical cataracts at the aeromedical examination may be missed unless dilated eye examination is carried out.

Rafnsson et al. (33) conducted a population-based case-control study using 71 pilots and 374 controls. Cataracts were quantified and graded according to World Health Organization classification and all participants completed a lifestyle questionnaire. Cumulative cosmic radiation doses were estimated for the pilot group. Cosmic radiation consists of ionizing subatomic (mainly proton and alpha) particles that do not form part of the electromagnetic spectrum. A higher prevalence of nuclear cataracts, which was attributed to cosmic radiation, was found within the pilot group. The two groups were not age-matched and the study group had a higher prevalence of smoking, a risk factor for nuclear cataract (24). No acknowledgment was made in the paper of the potential effect of UV radiation to the pilot population. Criticism was received (17) as the authors' estimated cosmic radiation doses were argued to be comparable with normal background levels.

Hammer et al. (19) reviewed the evidence of cancers in aircrew. An approximately twofold increased risk of melanoma was found in cohort studies. A weak link was found to cosmic radiation, but an established link was present between UV exposure and melanoma and non-melanoma skin cancers.

The European standard EN 1836:2005 sets out requirements for sunglasses. Within the requirements, there are four UV transmittance ratings. The highest UV protection rating of 7 means that no more than 5% of 380-nm radiation is transmitted. There is no rating for transmittance protection for radiation of up to 400 nm. Products which fulfill the standard receive a CE mark. However, these standards, unlike the Australia/New Zealand standard (AS/NZ1067:2003), may be self-certified by the manufacturer and there is no requirement for third party testing. Dain et al. (11) found that 1.8% of 646 CE marked sunglasses had excessive UV transmittance. The U.S. standard is the American National Standards Institute (ANSI) Z80.3-2001 standard which includes three transmittance categories. The lens should have a UV-B transmittance of no more than 1% and a UV-A transmittance of no more than 0.3 times the visual light transmittance.

There are a wide variety of sunglass lenses commercially available. Within the cockpit, the effectiveness of photochromic lenses, which react to UV radiation, will be reduced due to absorption properties of the windshield. As the lenses take longer to lighten, they may not react rapidly enough when descending through cloud. As polarizing lenses allow through light's transverse wave motion in only one direction (25), they can cause distortion patterns from some laminated cockpit windshields, render certain instrument displays invisible, alter cloud appearance, and reduce ground reflections useful for pilots.

No studies investigating pilot use of sunglasses were identified in peer-reviewed journals. A number of articles published in aviation magazines and electronically were identified. These articles (16,28,39,40) aim to offer guidance to a pilot or medical examiner and are summarized in **Table I** together with the CAA guidance material (7). All authors recommend against the use of polarized lenses by aircrew and warn against the potential drawbacks of photochromic lenses.

Rosenthal et al. (37) assessed the UV protection qualities of 32 pairs of 'discount price' sunglasses (16 glass and 16 plastic) purchased from drug stores in the United States. Measurements were taken with two separate UV detectors and a radiometer. A manikin head was used with a detector placed at the eye position behind a 4-mm and

TABLE I. SUMMARY OF RECOMMENDATIONS FOR PILOT SUNGLASSES.

	Source			
	CAA Guidance Material (7)	**Dully (16)**	**Montgomery and Nakagawara (28)**	**Spencer (39,40)**
Lens material	Not stated	Glass or polycarbonate	CR39 plastic or polycarbonate	CR39 plastic, glass or polycarbonate
Tint color	Gray or brown	One that allows short wavelength blue block, no color distortion, contrast enhancing without misrepresentation	UV blocking gray, gray-green or brown	Gray, green or brown
	Graduated tint may be useful		No appreciable color distortion	Graduated tint may be useful
Tint absorption	Up to 80%	Up to 75%	70–85%	80–85%
Spectacle frame	Well fitting		Sturdy, light, comfortable, compatible with headset	Comfortable fit
Photochromic lenses	Discouraged	Inappropriate	Discouraged	Try before buying
Polarizing lenses	Discouraged	Inappropriate	Inappropriate	Inappropriate
Other recommendations	Graduated tint. Lens large enough to allow sufficient protection from oblique sunlight	Optimum tint will vary between individuals. More than 1 tint may be needed during flight. 20% absorption yellow tint in low visibility	Small lenses not practical	Large lens. Tint should not completely block part of the visible spectrum

10-mm aperture. Readings were taken in natural daylight in a horizontal plane with and without sunglasses. Measurements were taken with the sunglasses fitted against the manikin forehead and repeated 'approximately 6 mm' away.

Results showed that UV exposure ranged from 0.8 to 14.1% with no difference between glass and plastic lenses. At the 6-mm position, the exposure ranged from 3.7 to 44.8%. No statistical analysis was carried out; however, the study did highlight the importance of frame fitting on sunglass selection.

DISCUSSION

Shorter wavelength radiation is more energetic, that is it has more energy per photon and is associated with a higher risk of cellular damage through photochemical reactions. The effect of solar exposure on ocular health has been extensively researched and there is strong evidence that UV radiation exposure is a risk factor for cortical cataract formation (9,27,44). The presence of cataract, even in early stages, can affect visual performance, particularly in low light conditions. It can reduce visual acuity as measured by a standard visual acuity chart, it can reduce the ability to see objects that have low contrast against their background (2), and glare may become troublesome because the cataract causes intraocular light scatter.

There is no good evidence in the literature indicating an increased prevalence of cataracts in airline pilots. However, the literature is limited and so this conclusion must be tentative. In particular, no study questioned pilots on their use of optical correction and sunglasses.

There is increasing evidence of retinal damage with prolonged UV or blue light exposure (1,10,13,46); however, there is no evidence available in the literature of the prevalence of AMD in civilian aircrew. Nakagawara et al. (29) demonstrated that at ground level, many airline cockpit windshields transmit a high percentage of light of wavelength over 320 nm (UV-A), but effectively block shorter wavelengths (UV-B). This does offer one explanation of the finding by Diffey and Roscoe (15) that pilots were exposed to insignificant levels of UV. The detectors used in the study were sensitive to wavelengths below 320 nm; however, these frequencies would have been blocked by the windshield, assuming it to be a similar design to that measured by Nakagawara et al. (29). Roscoe and Diffey's (36) study was unfortunately not followed up. Additional data addressing the variation of blue light levels with route, aircraft type, and time of day and year would be of great interest.

With a projected increase in UV in excess of 170% at cruise altitude compared to sea level, the transmission properties of airline windshields at altitude remain uncertain. While it seems likely that UV-B radiation remains negligible in the cockpit at altitude, significant levels of UV-A and short wavelength light around the blue light hazard (peaking at 440 nm) may be present. If this hypothesis is confirmed experimentally, one may not expect to find a significantly increased prevalence of cataracts due to occupational exposure within the airline pilot population. However, there may be a higher prevalence of retinal damage within this population.

Many pilots are required to wear corrective spectacles in order to meet the regulatory vision standards for flying. A degree of UV protection is offered from untinted prescription glasses. The lens material CR39 is commonly used and blocks UV radiation below 355 nm; crown glass blocks UV below 320 nm (21). Antireflection coatings on spectacle lenses, although transmitting more visible light, may reflect more UV radiation (6). Some soft contact lenses have UV blocking properties. Pilots may choose to wear prescription sunglasses in situations of bright light and glare. This should further enhance eye protection. Additionally, the use of aircraft sunshields and protective headwear may further reduce the level of short wavelength light entering the eye.

In conclusion, there is good evidence that long-term exposure to solar radiation, especially the ultraviolet and blue light components, is a risk factor for cataracts and, to a lesser extent, age-related degeneration of the retina. Pilots flying in daylight hours are exposed to solar radiation often for periods of many hours during a flight. Ultraviolet radiation is 2-3 times greater at cruising altitudes compared to sea level due to diminished atmospheric absorption. Reflectance from cloud tops also increases incident solar radiation. Pilots are protected by the aircraft windshield, which should absorb most ultraviolet radiation, but there are very few data to show they reliably do so. There is no standard for the optical transmission properties of aircraft windshields. There should be such a standard. Pilots can be additionally protected by ordinary spectacles, which generally absorb UV below 355 nm. They can also choose to wear sunglasses in bright conditions. CAA provides advice on the choice of sunglasses, but there are various national standards for sunglasses that not only ensure strong absorption of UV, but also have requirements for coloration to prevent the color of sunglass lenses distorting the color of aviation signal lights. Based on current available evidence, pilots could simply be advised to wear well-fitting sunglasses when flying in prolonged bright conditions and to make sure those sunglasses conform to a national sunglass standard.

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REFERENCES

1. Algvere PV, Marshall J, Seregard S. Age-related maculopathy and the impact of blue light hazard. Acta Ophthalmol Scand 2006; 84:4–15.
2. Bennett AG, Rabbetts RB. Clinical visual optics, 2nd ed, chapter 15. London: Butterworths; 1989.
3. Blumthaler M, Ambach W, Ellinger R. Increase in solar UV radiation with altitude. Journal of Photochemistry and Photobioly B: Biology 1997; 39:130–4.
4. Brilliant LB, Grasset NC, Pokhrel RP, Kolstad A, Lepkowski JM, et al. Associations among cataract prevalence, sunlight hours,

and altitude in the Himalayas. Am J Epidemiol 1983; 118:250–64.
5. Brown NP, Bron AJ. Lens disorders. A clinical manual of cataract diagnosis, chapter 9. Oxford: Butterworth-Heinemann; 1996.
6. Citek K. Antireflective coatings reflect ultraviolet radiation. J Am Optom Assoc 2008; 79:143–8.
7. Civil Aviation Authority. Guidance on using sunglasses. Civil Aviation Authority; 2008. Accessed: 24 November 2009 from: http://www.caa.co.uk/default.aspx?catid=49&pagetype=90&pageid=9244.
8. Civil Aviation Authority. AHU - Aviation health unit. Civil Aviation Authority; 2009. Accessed 24 November 2009 from: http://www.caa.co.uk/default.aspx?catid=923.
9. Cruickshanks KJ, Klein BE, Klein R. Ultraviolet light exposure and lens opacities: The Beaver Dam Eye Study. Am J Public Health 1992; 82:1658–62.
10. Cruickshanks KJ, Klein R, Klein BEK, Nondahl DM. Sunlight and the 5-year incidence of early age-related maculopathy - The Beaver Dam Eye Study. Arch Ophthalmol 2001; 119:246–50.
11. Dain SJ, Ngo TPT, Cheng BB, Hu A, Teh AGB, et al. Sunglasses, the European directive and the European standard. Ophthalmic Physiol Opt 2010; 30:253–6.
12. Darzins P, Mitchell P, Heller R. Sun exposure and age-related macular degeneration - an Australian case-control study. Ophthalmology 1997; 104:770–6.
13. Delcourt C, Carriere I, Ponton-Sanchez A, Fourrey S, LaCroux A, Papoz L. Light exposure and the risk of age-related macular degeneration: the Pathologies Oculaires Liees a l'Age (POLA) study. Arch Ophthalmol 2001; 119:1463–8.
14. Delcourt C, Cristol JP, Tessier F, Leger CL, Michel F, Papoz L. Risk factors for cortical, nuclear, and posterior subcapsular cataracts: the POLA Study. Am J Epidemiol 2000; 151:497–504.
15. Diffey BL, Roscoe AH. Exposure to solar ultraviolet radiation in flight. Aviat Space Environ Med 1990; 61:1032–5.
16. Dully FE Jr. Pilot's sunglasses: mystique or mandate. Flight Safety Foundation: Human Factors & Aviation Medicine. 1990; 37(4):1–4. Available at http://flightsafety.org/hf/hf_jul-aug90.pdf.
17. Facius R. No evidence for the causation by cosmic radiation of nuclear cataracts in pilots. Arch Ophthalmol 2006; 124:1369–70; author reply 1370-1.
18. Ham WT Jr, Mueller HA, Sliney DH. Retinal sensitivity to damage from short wavelength light. Nature 1976; 260:153–5.
19. Hammer GP, Blettner M, Zeeb H. Epidemiological studies of cancer in aircrew. Radiat Prot Dosimetry 2009; 136:232–9.
20. International Standard Organization. ISO 21348: space environment (natural and artificial) - process for determining solar irradiances. Geneva, Switzerland: ISO; 2007.
21. Jalie M. Materials for spectacle lenses: optical and mechanical performance. Optometry Today. 2005; 45(2):26–32.
22. Kagami S, Bradshaw S, Fukumoto M, Tsukui I. Cataracts in airline pilots: prevalence and aeromedical considerations in Japan. Aviat Space Environ Med 2009; 80:811–4.
23. Kanski JJ. Clinical ophthalmology: a systematic approach, 6th ed., chapter 17. Edinburgh: Elsevier Butterworth-Heinemann; 2007.
24. Kelly SP, Thornton J, Edwards R, Sahu A, Harrison R. Smoking and cataract: review of causal association. J Cataract Refract Surg 2005; 31:2395–404.
25. Millodot M. Dictionary of optometry, 2nd ed. London: Butterworths; 1990:110.
26. McCarty CA, Nanjan MB, Taylor HR. Attributable risk estimates for cataract to prioritize medical and public health action. Invest Ophthalmol Vis Sci 2000; 41:3720–5.
27. McCarty CA, Taylor HR. A review of the epidemiologic evidence linking ultraviolet radiation and cataracts. Progress in lens and cataract research. Dev Ophthalmol 2002; 35:21–31.
28. Montgomery RW, Nakagawara VB. Sunglasses in aviation: a primer for pilots. 2003; Federal Aviation Administration. Accessed 22 February 2011 from: http://www.faa.gov/library/reports/medical/fasmb/media/F2003_03.pdf.
29. Nakagawara VB, Montgomery RW, Marshall WJ. Optical radiation transmittance of aircraft windscreens and pilot vision. 2007; Federal Aviation Administration. Accessed 29 September 2009 from: http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA471609.
30. Nicholas JS, Butler GC, Lackland DT, Tessier GS, Mohr LC Jr, Hoel DG. Health among commercial airline pilots. Aviat Space Environ Med 2001; 72:821–6.
31. O'Hagan JB, Driscoll CMH, Pearson AJ. Occupational exposure to optical radiation in the context of a possibibe EU proposal for a directive on optical radiation. 2003; National Radiological Protection Board report W35. Accessed 29 September 2009 from: http://www.hpa.org.uk/web/HPAwebFile/HPAweb_C/1194947312809.
32. Pang J, Seko Y, Tokoro T, Ichinose S, Yamamoto H. Observation of ultrastructural changes in cultured retinal pigment epithelium following exposure to blue light. Graefes Arch Clin Exp Ophthalmol 1998; 236:696–701.
33. Rafnsson V, Olafsdottir E, Hrafnkelsson J, Sasaki H, Arnarsson A, Jonasson F. Cosmic radiation increases the risk of nuclear cataract in airline pilots: a population-based case-control study. Arch Ophthalmol 2005; 123:1102–5.
34. Rapp LM, Smith SC. Morphologic comparisons between rhodopsin-mediated and short-wavelength classes of retinal light damage. Invest Ophthalmol Vis Sci 1992; 33:3367–77.
35. Rebok GW, Qiang Y, Baker SP, Li G. Age-related vision problems in commuter and air taxi pilots: a study of 3019 pilots, 1987-1997. Aviat Space Environ Med 2007; 78:706–11.
36. Roscoe AH, Diffey BL. A preliminary study of blue light on an aircraft flight deck. Health Phys 1994; 66:565–7.
37. Rosenthal FS, Bakalian AE, Lou CQ, Taylor HR. The effect of sunglasses on ocular exposure to ultraviolet radiation. Am J Public Health 1988; 78:72–4.
38. Solanki V, Eperjesi F, Bartlett H. Ocular nutrition: part 2 - the blue-light hazard. Optometry Today. 2007; 47(16):30–8.
39. Spencer J. A good pair of shades. The Aviation Consumer. 2003; 33(4):8–32. Available through http://www.aviationconsumer.com/backissues/.
40. Spencer J. Sunglasses for pilots. The Aviation Consumer. 2003; 33(6):14–9. Available through http://www.aviationconsumer.com/backissues/.
41. Taylor HR, West S, Munoz B, Rosenthal FS, Bressler SB, Bressler NM. The long-term effects of visible light on the eye. Arch Ophthalmol 1992; 110:99–104.
42. Voke J. Radiation effects on the eye - ocular effects of ultraviolet radiation. Optometry Today 1999; 39(15):37–40.
43. West ES, Schein OD. Sunlight and age-related macular degeneration. Int Ophthalmol Clin 2005; 45(1):41–7.
44. World Health Organization. The effects of solar UV radiation on the eye. WHO/PBL/EHG/94.1. 1993; World Health Organisation. Accessed 24 November 2009 from: http://whqlibdoc.who.int/hq/1994/WHO_PBL_EHG_94.1.pdf.
45. World Health Organization. Ultraviolet radiation and health - environmental factors that influence the UV level. World Health Organisation; nd. Accessed 24 November 2009 from: http://www.who.int/uv/uv_and_health/en/.
46. Young RW. Solar radiation and age-related macular degeneration. Surv Ophthalmol 1988; 32:252–69.

Appendix B: Chorley, A. et al, (2013) Solar eye protection habits of civilian professional pilots.

Médecine Aéronautique et Spatiale

(Nouvelle appellation parue J.O.R.F. du 18 décembre 1985 p. 2464)

Ancienne Société Française de Physiologie et de Médecine Aéronautiques et Cosmonautiques fondée le 18 mai 1960 (J.O.R.F. du 30-31 mai 1960, n° 26, p. 4939)

La Société française de Médecine Aérospatiale (SOFRAMAS), association régie par la loi du 1er juillet 1901 a pour objet le développement et la diffusion des connaissances ainsi que de leurs applications en médecine aérospatiale (article 3 des statuts).
Ses moyens sont :
- l'organisation de séances consacrées à des conférences, à l'exposé de travaux cliniques ou expérimentaux se rapportant à la Médecine Aérospatiale.
- la publication de la Revue "Médecine Aéronautique et Spatiale"
- l'institution de missions d'études et de prix.

Solar eye protection habits of civilian professional pilots.

Habitudes de protection solaire des pilotes professionnels civils.

A. CHORLEY[1], B.J.W. EVANS[2] and M. BENWELL[3].

Articles reçus
Reviewed articles

Abstract

Aim: Research evidence supports the link between long term exposure to ultraviolet (UV) and short wavelength visible light and ocular damage including cataract and macular degeneration. Pilot population studies to determine the prevalence of these conditions are inconclusive. Previous studies have not considered whether pilots routinely use sunglasses during flight, which would offer a degree of protection from harmful optical radiation. The aim of this study was to gain an insight into the day to day eye protection practices of pilots operating various aircraft types.
Methodology: A series of 22 one to one interviews were conducted on experienced professional pilots. Data were transcribed and content analysis conducted.
Results: Sunglasses were worn a minority of the time during flight. Pilots requiring optical correction are less likely to use tinted lenses. Discomfort was the most common reason for not wearing sunglasses amongst those pilots not requiring optical correction. Aircraft visors are often used as the primary source of sunlight and glare protection. Pilots felt that the design of modern aircraft made it easier to manage high light levels. A number of other strategies were discovered which pilots may use in bright light conditions. There are additional considerations for the helicopter pilot.
Conclusion: Although aircraft visors may be used to shield eyes from direct sunlight, these are likely to be less effective than sunglasses at controlling levels of potentially harmful optical radiation reaching the eye. There was unawareness amongst participants of the potential ocular health effects of long-term exposure.

Keywords: Sun, Eye, Protection, Sunglasses, Airline, Pilots.

Résumé

Objectif: *Une enquête scientifique prouve le lien entre l'exposition prolongée aux ultraviolets, la lumière visible à longueur d'ondes courtes et les dommages oculaires y compris la cataracte et la dégénération maculaire. Les études faites sur les pilotes pour déterminer la prédominance de ces conditions restent sans conclusion. Les études précédentes n'avaient pas pris en considération le port par les pilotes de lunettes solaires pendant le vol, ce qui aurait permis d'offrir un niveau de protection contre les effets néfastes du rayonnement optique. Le but de cette étude était de connaître les méthodes de protection quotidiennes utilisées par les pilotes en fonction des divers types d'aéronefs.*
Méthodologie: *22 pilotes professionnels expérimentés ont été interrogés un par un. Les données ont été transcrites et le contenu analysé.*
Résultats: *l'usage des lunettes solaires pendant le vol était minimal. Les pilotes qui ont besoin des lunettes de vue sont moins susceptibles d'utiliser des verres teintés. L'inconfort était la raison principale, pour les pilotes sans correction visuelle de ne pas porter de lunettes solaires. Les visières d'avion sont souvent le premier choix de protection contre la lumière solaire et l'éblouissement. Les pilotes estiment que la conception des avions modernes facilite la gestion des hauts niveaux de lumière, mais il existe d'autres stratégies en particulier chez les pilotes d'hélicoptère.*
Conclusion: *Bien que les visières d'avion puissent être utilisées comme protection contre la lumière solaire directe, celles-ci sont probablement moins efficaces que les lunettes solaires pour limiter le niveau de rayonnement nocif atteignant l'œil. Les participants n'avaient pas conscience des effets oculaires causés par l'exposition prolongée.*

Mots-clés : Soleil, Œil, Protection, Lunettes solaires, Airline, Pilotes.

INTRODUCTION

Ultraviolet (UV) forms part of the electromagnetic spectrum. It is normally categorised into UV-C (200-290nm), UV-B (290-315nm) and UV-A (315-400nm)[1]. Radiation between around 400nm – 700nm reaches the human retina and is termed visible light. Short wavelength visible light is perceived as blue while the longer wavelength range of the visible spectrum is perceived as red.

Almost all solar UV-C is absorbed at high altitudes and UV-B is attenuated by the ozone (O3) which is generally concentrated within 15-50 km of the earth's surface [2]. However, levels of atmospheric UV and blue light increase with altitude (10-12% every 1,000 m)[2,3] and airline pilots may be receiving prolonged and increased exposure to potentially harmful radiation.

The absorption properties of aircraft windshields at ground level have been measured [4]. UV-B is almost completely absorbed. There is a percentage of UV-A radiation that may, depending on windshield type, be transmitted into the cockpit. For visible light between 400-600 nm, average transmittance was found to be over 80%.

Chronic exposure to UV radiation is known to cause ocular effects including cataract and pterygium [5-7]. Shorter wavelength radiation is more energetic and has a greater potential to cause photochemical changes to human tissue. Therefore, UV-B radiation is considered more harmful to health than UV-A radiation. Similarly, within the visible spectra, blue light is more energetic than longer visible wavelengths. There is evidence that prolonged exposure to light in the 440-450 nm range (the 'blue light hazard') can cause photochemical damage to the retina [8-10] which may lead to a loss of photoreceptor function and an acceleration toward macular degeneration and associated sight loss.

There is no published data of the prevalence of macular degeneration in the pilot population. There is insufficient evidence to determine if a greater prevalence of cataract is present in airline pilots. Age, smoking and diabetes are other risk factors for the development of this condition [7]. Although there are guidelines and recommendations for pilot sunglass selection [11-13], there are no published data on the actual use of sunglasses or other eye protection by pilots. If all pilots are using sunglasses at altitude, the prevalence of any radiation induced eye pathology is likely to be low.

There are a number of different types of sunglasses commercially available. The lenses are manufactured from either glass (such as crown glass) or plastic materials (such as CR39). The lenses can be dyed or coated to produce a fixed absorption tint. Different colour tints will have different spectral absorption profiles and darker tints will absorb a greater percentage of incident radiation. A tint may be manufactured to selectively absorb certain wavelength bands. Graduated tints are darker at the top of the lens, and lighter at the bottom of the lens. Photochromatic lenses darken when exposed to UV and may be manufactured from either glass or plastic materials. Polarised lenses offer absorption of visible light and reduce glare from light reflected off surfaces such as water.

Airline transport aircraft have protection in the form of visors in the cockpit to shield the sun from the pilot's eyes but it is not known to what extent they are used or what limitations they may have [14]. Additionally, there may be other eye protection strategies that are utilised to aid visual performance, visual comfort or give added UV and blue light protection. A bright light source such as the sun may cause an increase in scattered light within the eye which casts a veiling luminance on the retina, reducing contrast and affecting vision. This is known as disability glare [15]. The use of an eye protection strategy is likely to be initiated if the pilot becomes aware of disability glare. Discomfort glare can result from of an overly bright environment and may affect a pilot even when disability glare is controlled. Therefore, eye protection strategies may be initiated due to visual discomfort. Finally, it is also feasible that pilot concerns over ocular safety may initiate the use of eye protection strategies for solar protection. The aim of this study was to establish the extent to which sunlight may be an issue to commercial pilots and to explore the range and frequency of eye protection used.

METHOD

A series of semi-structured interviews [16] were conducted on current commercial and airline pilots. Participants were all Flight Operations Inspectors employed by the UK Civil Aviation Authority (CAA). Invitations to participate together with information sheets regarding the study were sent to all 28 inspectors employed by the CAA. For those individuals who did not initially respond, follow up contact was made at least twice by email or telephone.

Individual interviews were arranged with each study recruit. These were conducted in a private meeting room away from the work station of both participant and researcher. After verbally confirming the details of the study, participants signed a consent form before undergoing a one to one semi-structured interview with the researcher. Interview data were digitally recorded and stored in accordance with the UK Data Protection Act. The length of interview was typically between 20 and 40 minutes. Participants were questioned about their previous flying experience, their experience with sunlight in the cockpit and their coping mechanisms to manage this. Participants were also questioned on practices that had been observed in other pilots and any eye health concerns that they held regarding exposure to light within the cockpit.

Interviews were transcribed and data was subject to coding and content analysis[16]. The study had research ethical approval from London South Bank University and the Institute of Optometry, London.

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RESULTS

Twenty-two of the 28 (79%) flight operation inspectors participated in the study. Of the six who did not participate, 3 were based at regional offices around the UK and were unable to participate due to difficulties of geographical separation, 2 failed to respond despite at least 3 contacts and 1 was no longer flying and did not wish to participate. Fifteen participants were fixed wing (aeroplane) pilots and seven were rotary wing (helicopter) pilots. The average length of time over which a commercial or airline transport pilots licence was held was 27.4 years (range 12-43 years). Nine pilots also had additional previous military flying experience. Average flight time logged was 11,300 hrs for fixed wing pilots (range 6,700 to 17,000 hrs) and 6,400 hrs for rotary wing pilots (range 3,000 to 10,000 hrs).

There were a total of 31 fixed wing aircraft types flown consisting of five aircraft from the Airbus fleet, five from the Boeing fleet plus eight other jet airline aircraft, six business jet aircraft types, seven turbo prop commercial aircraft types. There were a total of 19 helicopter types flown and one airship type in addition to numerous general aviation instruction and aerobatic aircraft. Most pilots were currently flying more than one aircraft type.

1) THE VISUAL ENVIRONMENT

a. External

Certain conditions were reported as being associated with the issues with high levels of sunlight in the cockpit. These were dependent on where and when the aircraft was being operated and included bright sunny days, especially where light is reflected from cloud top, snow, or sea. Flying towards a low sun (sunrise and sunset), particularly in early spring and autumn, was consistently reported to be a discomfort or an irritation. A low sun in the cruise was easier to manage than a low sun on final phases of flight where the pilot is using visual cues outside the aircraft to make a safe approach to land. A low sun on final approach was reported to cause a loss of visual references, loss of depth perception, a harsher flare and a higher stress approach. As well as direct sunlight, pilots also reported difficulties with sunlight from the side of the aircraft reflecting off the instruments making them less easy to interpret. It was generally acknowledged that this was less of an issue with more modern LCD instrument displays. A bright sun through an atmospheric interference such as haze, where the glare source is increased in size through scatter, was also reported as a difficult flying condition.

Although sunlight was recognised as a cause of visual irritation, discomfort and fatigue, pilots report coping mechanisms such as increase use of autopilot, instrument flying, using peripheral airfield visual cues or landing on a runway not into sun. It was not felt that there was a flight safety issue although pilots felt that it was less of an issue for them with increased experience. *"...the cues aren't as obvious as if you weren't suffering from all that glare. I can't see that it's a flight safety issue, its more common sense and good airmanship to avoid those situations if you can."*

b. Internal

Most aircraft have sun protection fitted as standard for the pilot to reduce the levels of bright sunlight in the cockpit. Newer aircraft types and fits were reported to have a more comprehensive protection offered. Large commercial airline transport aircraft have semi-opaque roller blinds on side windows and a hinged adjustable visor in front of each pilot. Although it was felt that improvements had been made to visors protection, a number of comments were made that manufacturers could make further improvements. However, there was no consensus of opinion as to how this could be achieved. Pilots had concerns if visor were too small and did not offer sufficient coverage or were too large and obscured look out.

Some aircraft types were acknowledged as better at offering sunlight protection due to the smaller size of the windows, the thickness of window frames and the depth of instrument combing. Different business jets were reported to have a wide variation in the level of visor protection offered, with some aircraft having no visors. These aircraft may be operated at higher altitudes than airline transport aircraft resulting in a potential increase in pilot exposure during flight.

Although instrument lighting can be adjusted for optimum viewing under light and dark conditions, it was reported that the range was not sufficient for very bright environments. Where instrument lighting was set toward its maximum level, a greater discrepancy between brightness of different instruments and an increase in time to interpret more complex displays were reported.

c. Additional considerations for helicopter pilots

Study participants revealed that many helicopter types have little or no standard fitted visor protection. However, operating altitudes are lower (often below cloud) and flight duration may be short so that no prolonged single leg flying into sun is likely. Additionally, the helicopter offers more flexibility to position the aircraft away from sun on an approach to land.

Comments were made from helicopter pilots that bright sunlight may make visual height judgement more difficult transiting from hover into forward flight. Additionally, where precise manoeuvring near the ground is required, the effect of moving from light into shade was recognised as more challenging. Those pilots operating offshore (e.g. to oil platforms) reported, in direct sunlight, that instruments became difficult to interpret due to reflections from the instrument surface of their high visibility jacket.

Helicopter pilots felt that the environment in which they operated was less ideal than that of the airline pilot. Commenting about visors: *"...they vibrate and fall out of the way so you tend to find a place where they won't move again and just leave them there and use those – that tends to be the modus operandi in the North Sea."*

"Helicopter pilots tend to accept their lot in many ways, the vibration, the noise and discomfort and all the other effects you get, being dazzled and blinded by sunlight is just another one of those things that you put up with!"

2) COPING STRATEGIES USED

a. Sunglasses

The proportion of flight time where

sunglasses were used varied widely in the pilots interviewed. Many of those interviewed reported using sunglasses for a minority of the time and only in those conditions where sunlight and subsequent disability or discomfort glare was reported as most apparent (in the cruise, flying into low sun and landing and take-off into sun).

A difference was found between those pilots who require corrective prescription glasses for aviation and those who do not. All pilots (both fixed wing and rotary) not requiring glasses constantly (n = 11) used sunglasses at least sometimes in flight. Of those who required corrective spectacles (n = 11), five never used sunglasses.

A number of reasons including hassle and distraction in swapping glasses (particularly in single crew operations) were given as reasons for sunglasses not being used. *"I imagine that if you're like me with varifocals, any pair of sunglasses with varifocals would be quite expensive – that's one issue. I think just the hassle would be the other thing."*

"I think people like me with a prescription, wear clear specs and those without prescription wear RayBan, or something, so I think having prescription specs is a disability if you like in terms of mitigation of glare. I could get a pair of sunspecs which are varifocals but again they are either on or they're off, there's a distraction element."

The onset of requirement for glasses was a further factor for discontinuing use of sunglasses. *"I wish I had a solution to my own situation of just wearing clear specs all the time 'cos there are many occasions where I wish I had some sort of tinted glasses to wear but I don't have a ready solution. I've either got a pair of prescription specs that I have got to buy which are varifocal that I put on or take off, and for me that's not as workable solution as it should be."*

Comfort was the most consistent factor reported in whether sunglasses were worn amongst the non-spectacle wearers. Sunglasses were reported as uncomfortable over a period of time due to pressure of the sides of the frames on the head, discomfort behind the ear, poor compatibility with the headset or the onset of headaches. However, when questioned, most pilots had not had their sunglass fitting checked or adjusted. Thin, lightweight, comfortable frames were reported as the main requirements for a pair of sunglasses.

Pilots reported that the effect of a sunglass filter made the instruments harder to interpret. Some pilots reported that subsequent sunglasses purchased had a lighter tint for this reason. It was also reported by two interviewees, that they felt their depth perception was affected with sunglasses and that a degree of separation was experienced to the outside world. These pilots would tend to use sunglasses less and remove them in critical phases of flight such as approach and landing.

Other reasons given for not using sunglasses included that they were forgotten, that the individual was not flying frequently and that glare was more subjectively apparent during other tasks (such as sailing, skiing or driving). Additionally, pilots who had previously worked overseas in sunny climates, reported using sunglasses more at that time and less now that they were based in the UK.

Sunglasses used by the study participants were assessed and varied between 50-85% absorption (estimated against tint samples of known absorption) and were generally standard fixed green, brown or grey colour. There were no graduated tints. Two pilots had polarised lenses and one had photochromatic lenses, neither of which are recommended for pilots by the CAA[11]. These three pilots all required spectacle correction. Of the pilots not requiring prescription spectacles, the brand of sunglasses that was used most commonly was RayBans (6/10). Most pilots had no preference for a specific tint colour; of those that did specify a preference (3/22), no consistent tint colour was reported, indicating that it was personal preference.

b. Use of standard aircraft protection system

A wide range of sun protection was offered in the form of visors and sun blinds in the various aircraft types flown by the study group. Generally it was felt that newer aircraft designs and fits offered a more comprehensive and flexible sun protection system. The sun screens were often larger and covered more of the window area. Additionally, modern instruments such as those using LCD displays were consistently reported to be more visible in bright light conditions. Flexibility in instrument and interior lighting also assisted pilots to gain a comfortable visual environment.

Pilots described an annoyance if the aircraft visors were not properly maintained and would tend to use sunglasses more on these occasions. Visors were often seen as the primary eye protection aid; sunglasses were then used in situations where the pilot felt the visors were not able to provide sufficient light attenuation. Anecdotally, there were more positive remarks made concerning the Airbus sun visor system compared to that of the Boeing fleet.

c. Adaptation to aircraft protection system

Some practices to protect the pilot from sunlight were described which involved a form of adaptation to the existing fitted aircraft visor system. These would take the form of newspapers, charts, tray liners or semi-opaque plastic sheets either stuck against the windshield or attached to the lowered visor (with spring clips or elastic bands) to increase the area of windshield able to blocked the sun. This practice would be carried out in cruise with traffic collision avoidance system (TCAS) active and generally during long haul flights when pilots may be more fatigued and in circumstances of flying towards a low sun. It was also a method used to reduce temperature in the cockpit. It was felt to be an older practice and declared only by airline transport pilots.

Another practice declared during cruise was to adjust the seat so that the sun was less in the pilots'eyes. This may entail moving the seat to place the sun behind part of the aircraft structure or visor. Some pilots felt that this was an unsafe practice as the pilot would lose full range of control movements and alter the visual aspect over the cowling.

d. Other practices

A number of other practices were described to shield the eyes from bright sunlight. These included the use of baseball caps. This was a preferred protection method for helicopter pilots

where there may be little or no protection offered in the aircraft. Additionally the peak of the baseball cap would offer complete block of sunlight and reduce any distraction from light flicker of sunlight passing through the helicopter rotor blades. Some airline pilots also reported baseball caps useful during climb and descent where charts and newspapers to block windows could not be used.

Further practices reported included using hand or fingers to obscure direct sunlight or eyelid squinting or avoid looking into the sun.

Some police helicopter pilots used helmets that incorporate an integral visor which could be employed when required.

e. General

Aircraft visors were often seen as the primary eye protection strategy. It was felt that visors were more effective than sunglasses in direct bright light, but that the glare source may not be covered by a visor. It was also felt that visors reduced lookout ability.

It was commented that sunglasses may help detecting ground features and other aircraft but detract from seeing instruments.

It was felt that there is no ideal solution that works for all situations. Protection from sunlight involved compromise and pilots manage sunlight as they would other aspects of flight management. *"everything has to be done at an appropriate time. I suppose 75-80% of the time, the actual designed sun visors are sufficient and other times you've got to be a little bit more ingenious... or put your sunglasses on, which is what I tend to do".*

f. Other observed practices

As Flight Operations Inspectors, the pilots interviewed in this study flew with various airlines and pilots as part of their role. Both extremes of sunglass use (never used to full time wear) were observed in other pilots during day flights. One pilot was observed with different sunglasses for low altitude and cruise. Clip on, flip up sunglass shades were observed as well as a pair of sunglasses worn over a pair of prescription clear glasses.

The use of newspapers or charts to block out sunlight during (long haul) cruise was seen, but less so with time. This may be due to an improvement in aircraft visors or because the presence of a CAA inspector on board discouraged it. It was recognised by 4 participants as not best practice although it was not considered an impact to flight safety in that controlled environment.

3) Eye health

When questioned, 17 of the 22 interviewed did not express any anxiety or concern over the possibility of sunlight causing eye health problems. Three responded affirmatively and the remaining two did not give a definitive answer.

Some reported that they had other, non eye-related health concerns through flying such as sunlight exposure to skin, noise induced hearing loss and vibration. Those flying low level (helicopters) or infrequently did not have eye health concerns.

Of the three pilots who did have health concerns, two admitted to having the development of cataract and that they were subsequently more concerned of their eye health because of this.

Additionally, two pilots declared an assumption that the aircraft windshield would offer the required level of eye protection.

Discussion

Pilots describe both disability and discomfort glare during flight. The use of eye protection strategies (e.g. sunglasses) is initiated by subjective symptoms of glare. Overly bright glare conditions act as a disruptive factor to a pilot's operational workload although it was not considered a flight safety hazard.

Modern aircraft are described as being better equipped in terms of visors and instrumentation for bright light conditions. More flexible use of visors and sun blinds offer a larger area of sun protection including sunlight from the side of the aircraft. The advent of LCD instrument displays with low reflection screens reduce the level of sunlight reflection on instrumentation making these more visible and quicker to interpret by the pilot. There are some aircraft where sun glare protection is minimal or nonexistent. Often, these aircraft operate for short duration and at low level where UV and blue light hazard levels are likely to be low. However, one type of flight operation where exposure may be high is for the business jet pilot flying at high altitudes in an aircraft with little or no visor protection.

Sunglasses appear to be worn only a minority of time. When sunglasses are used, it is primarily for visual comfort (to reduce discomfort glare) and on occasions to aid visualisation of the task (to reduce disability glare). Sunglasses are not primarily worn by a pilot for solar radiation protection or eye health considerations. Additionally, the sunglasses used by the pilot to reduce disability or discomfort glare may not offer optimum solar protection. Further research to explore levels of irradiance of near visible UV and blue light hazard wavelengths at altitude within the cockpit will aid the assessment of risk to a pilot.

Aircraft visors are often considered the first choice aid to manage glare within the cockpit. Although visors will shield the eyes from a direct glare source, there is not total windshield coverage and there could still be high levels of UV and blue light present within the cockpit.

Sunglasses are likely to be the optimum method to control the amount of UV and blue light hazard radiation entering the eye. One reason given in this study for not using sunglasses during flight was due to the perceived reduction of visibility of aircraft instruments when viewed through a tinted sunglass lens. Light reaching a pilot's eye from below (such as reflected light from cloud top or snow) is likely to be largely blocked, in the case of an airline transport pilot, by the aircraft structure and instrument cowling. Therefore, the use of a graduated tint should aid instrumentation visibility. However, in this study, no pilots were found to be using this type of tint.

Those interviewed in this study are experienced pilots. This may not be representative of the entire professional pilot population and younger

pilots may express different views or have other concerns. The view expressed from those interviewed was that with experience the increase in workload associated with challenging conditions was easier to manage.
The prevalence of cataract increases with age. This has the potential to cause disability glare through increased intra-ocular scatter and reduced retinal image contrast [17]. Retinal macula pigment has not been found to decrease significantly with age [18] but is reduced in those with macular degeneration. Discomfort and disability glare have been shown to be increased with reduced macula pigment [19]. Additionally pupil size, which generally decreases with age, is associated with higher level of discomfort glare [19]. Therefore, older pilots are more likely to be affected by glare. Younger pilots of the internet generation may be better informed with regard to eye health.

It appears that the requirement for wearing corrective glasses is a major factor as to whether a sunglass tint is used by pilots. Those pilots who have worn spectacles throughout their flying career often feel to be disadvantaged in using sunglasses. A number of pilots interviewed had ceased using sunglasses since the advent of their need for corrective spectacles. This is particularly surprising since glare problems from sunlight are likely to increase with age. The interviews show that sunglasses assist at alleviating glare and that the reduced use of sunglasses (or tinted prescription glasses when pilots require prescription spectacles) is associated with increased problems from glare, and most likely an increased risk of ocular pathology associated with light exposure.

The majority of prescription spectacle lenses are made from a plastic material such as CR39. This material transmits most of the visible spectrum but blocks UV radiation below 355 nm; crown glass is used less commonly and blocks UV below 320 nm [20]. Therefore, some degree of protection will be offered although it is unlikely that significant protection from the blue light hazard will be afforded. As spectacle wearers are less inclined to wear prescription sunglasses due to the distraction element of changing glasses in flight, the development of a minimally tinted lens material with UV and blue light hazard protection would be beneficial.

There is some anecdotal evidence that many pilot applicants embark on training immediately after leaving school or university whereas a few decades ago, airline flying may have been a second career with applicants applying at a later age. Therefore, newly qualified pilots may receive a longer lifetime exposure than the older generation. Additionally, modern aircraft are more aerodynamically efficient and are able to operate at higher altitudes for longer duration flights than older aircraft types. This also has potential to increase lifetime exposure to UV and the blue light hazard. Previous studies attempting to measure this radiation in the cockpit at altitude are limited [14].

Conclusions

Pilots tend to use aircraft visors as the primary means of eye protection from sunlight in the cockpit. Sunglasses are worn a minority of the time and, in non spectacle wearers, the main reason for not wearing sunglasses appears to be discomfort (e.g., from the fit of the frame with headgear). This potentially exposes pilots to increased UV and blue light hazard exposure although the range and intensity of non-ionising radiation in the cockpit at altitude has not been clearly established.

As pilots do not tend to show an awareness of eye health issues related to sunlight exposure, it is prudent for healthcare professionals to give advice on the importance of eye protection and to ensure that sunglasses are light, well fitting and compatible with task. The advantages of a graduated tint should be considered.

Références

1 International Standard ISO 21348. Space environment (natural and artificial) - Process for determining solar irradiances. Geneva, Switzerland: ISO; 2007.

2 BLUMTHALER M, AMBACH W, ELLINGER R. Increase in solar UV radiation with altitude. *J. Photochem. Photobiol. B: Biol* 1997; 39: 130-134.

3 World Health Organisation. Ultraviolet Radiation and Health - Environmental factors that influence the UV level. World Health Organisation. Accessed 16 November 2012 from: http://www.who.int/uv/uv_and_health/en/.

4 NAKAGAWARA VB, MONTGOMERY RW, MARSHALL WJ. Optical Radiation Transmittance of Aircraft Windscreens and Pilot Vision. Accessed 16 November 2012 from: http://www.dtic.mil/dtic/tr/fulltext/u2/a471609.pdf

5 World Health Organisation. The effects of Solar UV Radiation on the eye. 1993. WHO/PBL/EHG/94.1. 1993; World Health Organisation. Accessed 16 November from: http://apps.who.int/iris/bitstream/10665/62584/1/WHO_PBL_EHG_94.1.pdf

6 CRUICKSHANKS KJ, KLEIN BE, KLEIN R. Ultraviolet light exposure and lens opacities: the Beaver Dam Eye Study. *Am J Public Health* 1992; 82: 1658-62.

7 DELCOURT C, CRISTOL JP, TESSIER F, LEGER CL, MICHEL F, PAPOZ L. Risk factors for cortical, nuclear, and posterior subcapsular cataracts: the POLA study. Pathologies Oculaires Liees a l'Age. *Am J Epidemiol* 2000; 151: 497-504.

8 DELCOURT C, CARRIERE I, PONTON-SANCHEZ A, FOURREY S, LACROUX A, PAPOZ L. Light exposure and the risk of age-related macular degeneration: the Pathologies Oculaires Liees a l'Age (POLA) study. *Arch Ophthalmol* 2001; 119: 1463-8.

9 WEST SK, ROSENTHAL FS, BRESSLER NM, BRESSLER SB, MUNOZ B, FINE SL, *et al.* Exposure to sunlight and other risk factors for age-related macular degeneration. *Arch Ophthalmol* 1989; 107: 875-9.

10 YOUNG RW. Solar radiation and age-related macular degeneration. *Surv Ophthalmol* 1988; 32: 252-69.

11 Civil Aviation Authority. Guidance on using sunglasses. 2008. Accessed 16 November 2012 from: http://www.caa.co.uk/default.aspx?catid=49 & pagetype = 90 & pageid = 9244

12 SPENCER J. Sunglasses for Pilots. *The Aviation Consumer* 2003; 33: 14-19.

13 MONTGOMERY RW, NAKAGAWARA VB. Sunglasses for Pilots: Beyond the image. Federal Aviation Administration. Accessed 16 November from: http://www.faa.gov/pilots/safety/pilotsafetybrochures/media/sunglasses.pdf

14 CHORLEY AC, EVANS BJ, BENWELL MJ. Civilian pilot exposure to ultraviolet and blue light and pilot use of sunglasses. *Aviat Space Environ Med* 2011; 82: 895-900.

15 MAINSTER MA, TURNER PL. Glare's causes, consequences, and clinical challenges after a century of ophthalmic study. *Am J Ophthalmol* 2012; 153 (4): 587-93.

16 BOWLING A. Research methods in health. Buckingham: Open University Press; 2002. p 257-272, p 336-350, p 378-401.
Ref Type: Generic

17 BROWN NA. The morphology of cataract and visual performance. *Eye (Lond)* 1993; 7 (Pt 1): 63-7.

18 CIULLA TA, HAMMOND BR, Jr. Macular pigment density and aging, assessed in the normal elderly and those with cataracts and age-related macular degeneration. *Am J Ophthalmol* 2004; 138: 582-7.

19 STRINGHAM JM, GARCIA PV, SMITH PA, McLIN LN, Foutch BK. Macular pigment and visual performance in glare: benefits for photostress recovery, disability glare, and visual discomfort. *Invest Ophthalmol Vis Sci* 2011; 52: 7406-15.

20 JALIE M. Materials for spectacle lenses: optical and mechanical performance. *Optometry Today* 2005; 45: 26-32.

Prochaines réunions prévues en 2013

Ce programme est présenté à titre prévisionnel - Consultez régulièrement le site pour l'actualiser.

DATE et LIEU	THEME
Vendredi 6 juillet 15ème EMAM	
Vendredi 13 septembre Toulon	Thème : L'Evidence Base Medicine est-elle applicable en médecine aéronautique ? - BOUVENOT : EBM : Base et principes. - E. CZERNIAK : Causes médicales en accidentologie aéro et incapacités médicales en vol. - M. MONTEIL : Un questionnaire serait-il suffisant en expertise aéronautique. - FX. BROCQ : Comment mettre une pincée d'EBM dans vos expertises aéronautiques ? - C. RIVIERE (angiologue) : Apport de l'angiologie dans le dépistage et la prise en charge du risque CV.
6-10 octobre Jérusalem 61ème ICASM	- JF. PARIS : Grossesse et pilotage : le point depuis son autorisation en France. - J. COUTURIER : Intérêt de l'examen clinique ORL en expertise aéronautique. - M. MONTEIL : Missions aériennes médicalisées et prise de risque. La perception des pilotes.
Jeudi 17 octobre Communications Libres	- P. CREPY : CRDSC syndrôme. - S. BISCONTE : sujet à définir. - O. MANEN : sujet à définir.
Jeudi 21 novembre Communications Libres	- F. FROUSSARD MAILLE : Oeil et Espace : Actualités. - MONIN : sujet à définir. - JM CLERE : le NASTAR Center : une nouvelle façon de concevoir la médecine aéronautique et spatiale.
Jeudi 19 décembre	AG : Conférence - L'hélicoptère X3 par Mr JAMMAYRAC, pilote d'essai.

Appendix C: Chorley, A. et al, (2014) Measurements of Pilots' Occupational Solar UV Exposure.

Photochemistry and Photobiology, 2014, 90: 935–940

Measurements of Pilots' Occupational Solar UV Exposure

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ABSTRACT

It is known that ultraviolet radiation (UVR) increases by 10–12% every 1000 m altitude; UVR at the 10 000 m of typical cruise altitude for commercial aircraft may be 2–3 times higher than at ground level. Information on the levels of solar UV exposures is essential for the assessment of the occupational risk of pilots developing sun-related eye disorders and skin cancers. The aim of the study was to investigate how UV hazard exposures can be measured during flights so that the occupational dose can be ascertained and compared with international guidance. This article describes the development of instrumentation for automated time-stamped spectral measurements which were collected using bespoke automation software. The software enables the advanced acquisition techniques of automated dark signal capture and multiband integration control optimizing the dynamic performance of the spectrometer over the full spectral range. The equipment was successfully tested in a number of aircraft and helicopter flights during 2012–2013 and illustrated in this article on an example of a Gatwick-Alicante flight.

INTRODUCTION

It is known that ultraviolet radiation (UVR) increases by 10–12% every 1000 m altitude (1); UVR at the typical cruise altitude of commercial aircraft, 10 000 m, may be 2–3 times higher than at ground level. Ocular exposures may further increase due to reflectance from clouds as water reflects both the direct UVR from the sun as well as the diffuse component from the entire sky. Research addressing the prevalence of UVR related ocular pathology in the professional pilot population is limited and inconclusive (2). Investigation of the eye protection habits of professional pilots (3) shows a wide variation in the use of sunglasses during flights. In addition, there is some evidence of an increased prevalence of melanoma in professional pilots (4). Information on the levels of solar UV exposures is essential for the assessment of the occupational risk of pilots developing sun-related eye disorders and skin cancers.

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has issued exposure limit guidelines for both UVR and Blue Light hazards (5,6). The Exposure Limit Values (ELVs) take into account the biological effectiveness of the optical radiation in causing harm at different wavelengths, the duration of exposure to the optical radiation and the target tissue. The ELVs represent levels at which ICNIRP considers most of the working population can be repeatedly exposed without suffering any acute adverse health effects and without demonstrated risk of long-term effects.

To protect the eye from UV induced cataract, a maximum radiant UV-A (315–400 nm) exposure for the eyes within an 8 h working day should not exceed 10 kJm^{-2}. The ICNIRP guidelines recommend that the UV-A limits be considered as "ceiling values" for the eye and ELVs are directly applicable to exposure of the cornea under worst-case conditions of normal incidence (7).

Previous research investigating civilian pilot exposure to UVR and Blue Light hazards is limited (8,9). Diffey and Roscoe (8) measured erythema-weighted radiant exposure during flights using polysulfone film badges worn by pilots on the epaulette nearest to the side window. Recordings were taken from the captain and first officer on 12 flights, including long and short-haul on a wide variety of routes worldwide; the total exposure during flight was then measured from the badge. The results showed that maximum exposures did not exceed 0.019 MED h^{-1} and were significantly less than the doses on unshaded horizontal surface at ground level: 2.3 MED h^{-1} in Adelaide (35° S, March) or 0.73 MED h^{-1} in Newcastle (55° N, partial clouds, June). It was concluded that annual occupational exposure of four MEDs is negligible and civilian aircraft offer virtually complete protection from biologically damaging UVR.

As spectral sensitivity of polysulfone dosemeters is restricted to the wavelengths shorter than 330 nm (10), they are not suitable for UV-A measurements; radiant exposure from solar radiation filtered by the aircraft windscreen may be underestimated if measurements do not include the contribution from the UV-A component. Furthermore, polysulfone films register total radiant exposure and do not contain spectral information or dose rate. These data cannot be correlated to flight log or used for providing evidence-based guidance on eye protection.

Roscoe and Diffey (9) also used a sensor comprising an internally baffled barrel with 2.5° field of view and blue light filter, 370–520 nm, to measure blue light in a cockpit. During a 2 h 15 min flight from Gatwick to Malaga, a wide variation in radiance was found depending on the direction of flight; the authors concluded that the blue light hazard was similar to that at ground level pointing up at a clear sky.

To carry out detailed assessments of pilots' exposure under different flight conditions, time-stamped spectral data are needed.

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This could be related to flight details, such as duration, direction of flight, altitude and cloud cover. Miniature CCD array spectroradiometers are increasingly used in a range of applications where rapidly changing spectral information is required to be captured as a function of time, such as in phototherapy dosimetry (11), solar monitoring (12) or measurement of emissions from sunbeds (13,14). Although CCD array spectroradiometers offer many advantages, they suffer from stray light (15) and variation in characteristics with ambient temperature (16). Guidance on their use for measuring solar UV spectra (17) recommends temperature control and automated dark signal acquisition.

The constraints of aircraft cockpits and the operational requirements of commercial flights apply additional restrictions on the use of spectroradiometers for the assessment of pilots' exposure:

1 The confined space rules out temperature control of the instruments;
2 The equipment should not cause interference with aircraft electronics or compromise flight safety;
3 The input optics and light guides may pose an obstruction to pilots if placed near the face;
4 All instrumentation must be independently powered for the duration of the flight.

The aim of this study was to investigate how UV exposures can be measured during flights so that the occupational dose can be ascertained and compared with international guidance. This article describes the design of instrumentation, its limitations and illustrates an example of its successful operation on a flight from Gatwick to Alicante.

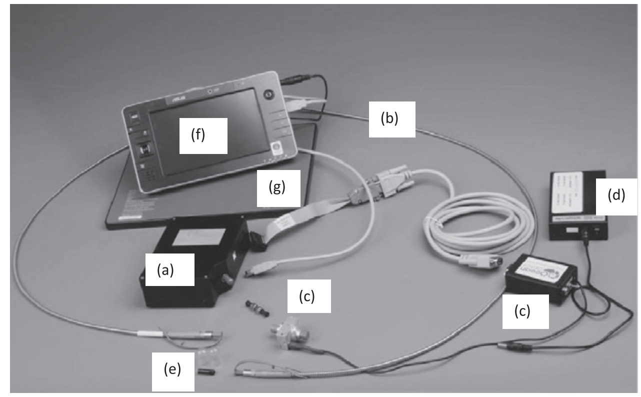


Figure 1. Components of automated measurement equipment: (a) HR4000 spectroradiometer, (b) optical fiber, (c) in-line TTL shutter with control box and power supply, (d) shutter battery, (e) CC-3-UV diffuser, (f) palmtop computer, (g) battery.

Figure 2. TR-74Ui Illuminance UV Recorder.

MATERIALS AND METHODS

At any given time, in the absence of additional filters or screens, the shape of the transmitted solar spectrum remains the same and it is independent of the distance from the windscreen, that is the intensity changes but the relative percentage of individual spectral regions remains the same. In other words, UV-A, erythema and Blue–Light-weighted irradiance follow illuminance, and the illuminance is unambiguously linked to the hazard level. It is, therefore, possible to reconstruct UV-A, erythema and Blue–Light-weighted irradiance from measured illuminance using a broad-band instrument if spectral measurements are simultaneously taken at a different distance from the windscreen (18,19).

In order not to compromise safe flight operations, it was proposed that measurements of spectral irradiance be carried out at specified times at a fixed position in the cockpit in close proximity to the front aircraft windscreen. Time synchronized broad-band illuminance measurements would be taken near the pilot's face representing typical tasks during flight. Using broad-band illuminance data and spectral irradiance from spectral measurements, UV-A, erythema and Blue–Light-weighted irradiance may then be determined from the ratio of illuminance at these locations.

Measurement hardware. The accessible solar emission was measured over the spectral range of 280–1100 nm using a miniature CCD array spectroradiometer HR4000 (Ocean Optics Inc, Dunedin, FL), S/N HR4C1877, equipped with 25 μm entrance slit and HC1 grating. It was coupled by a metal jacketed QP600-2-SR/BX optical fiber to a CC-3-UV diffuser, see Fig. 1.

For fully autonomous operation of equipment during flight, an in-line INLINE-TTL-S fiber shutter was connected directly to the spectroradiometer by RS232. The shutter enabled a dark measurement to be carried out immediately after every data acquisition. The spectroradiometer and TTL shutter were controlled by automation software installed on an ASUS R2E palmtop (Windows Vista operating system) connected to the spectroradiometer through a single USB computer cable. An XCell Pro battery enabled more than 8 h continuous operation of the palmtop and the HR4000; for longer flights a second battery was available. A YSN-12680 12 VDC battery was used to power the optical shutter.

Two miniature TR-74Ui Illuminance UV Recorders (T&D Corp, Japan) shown in Fig. 2 were used to record illuminance data that were time-synchronized with spectral measurements. One unit was at a fixed position (set for automated readings), side-by-side with the input optics of the HR4000; the other was used by a researcher taking manual readings from an additional fold down seat located between the pilots' seats known as the aircraft "jump seat". These readings were taken at the level of the pilot's face to measure ocular exposure when looking straight ahead out of the cockpit and angled down to measure ocular exposure when looking toward the primary aircraft instrumentation. A maximum obtainable illuminance reading in the cockpit was also taken. These illuminance data and spectral irradiance from spectral measurements were then used to calculate UV-A and Erythema-weighted irradiance for the assessment of ocular safety for the flight.

An assessment was carried out prior to flight to ensure that the equipment did not interfere with any aircraft systems and that the airline captain (responsible for the safe conduct of the flight) approved of the positioning and securing of the equipment for flight.

Accuracy of wavelength calibration of the HR4000 was verified before and after each flight by a low pressure Hg pen-ray lamp; Fraunhofer lines were used for confirmation of wavelength stability of in-flight data. The system was calibrated and its performance was monitored over the duration of this study in a laboratory controlled environment using 1000 W tungsten-halogen lamps, calibrated for spectral irradiance to the Physikalisch-Technische Bundensanstalt (PTB) traceable reference standards. For the analysis of the in-flight exposures and to minimize contribution of stray light, the spectroradiometer was additionally calibrated to the solar spectral irradiance at solar noon on a clear day during mid summer, using a scanning double-grating monochromator D^3 180 (Jobin Yvon, Longjumeau, France) as a reference instrument.

It is important for solar measurements that the input optic is able to collect radiation at different angles. The angular response of the CC-3-

UV diffuser was measured using a collimated 100 W tungsten-halogen lamp at angles ranging from −80° to +80° in 5° intervals. For the incident angles (±30°), the input optic of the spectral system matches the cosine response within 5% and is constant with wavelength. At 40°, the input optic throughput is approximately 9% lower. The angular response of TR-74Ui Illuminance UV Recorder is similar; the cosine response error is 6% at ±30° and 8% at ±40°. ICNIRP guidance (7) states that for the eye hazard assessment, the detector field of view can be reduced and limited to 80° (±40° from the normal). Angles of incidence higher than 40° are restricted by the cockpit structure and so the angular response of the instrumentation is considered to be suitable for this application.

It is known that the performance of CCD array spectroradiometers is affected by variations in ambient temperature (15). Constraints of in-flight measurements rule out the possibility of operation of the instrument in a temperature-controlled environment. To evaluate temperature effects, wavelength position, sensitivity and structure of background signal were measured at the range of foreseeable operation temperatures from 10°C to 40°C.

Elevated ambient temperature causes blueshift of wavelength position, exceeding 0.5 nm at 40°C. The sensitivity change with temperature between 22 and 35°C is relatively small, within 2–3%, with respect to the sensitivity at 22°C. However, the mean of dark signal and the standard deviation of the dark signal both increase significantly with increasing integration time above 100 ms and with increasing ambient temperature. A sharp increase in dark signal, and, as a result, loss of signal-to-noise ratio at elevated temperatures for this instrument is a major limiting factor of use outside a temperature-controlled environment. A dark measurement taken immediately after measuring the signal mitigated this effect.

It was shown that thermal equilibrium of the HR4000, for example instrument internal temperature, lagged behind the change of ambient temperature for up to 30 min. Therefore, monitoring ambient temperature during field measurements with this particular instrument may be highly inaccurate if ambient temperature used for correction of its performance. The instantaneous board temperature which relates to the internal temperature of the HR4000 was a better and more dynamic predictor of spectroradiometer characteristics than ambient temperature when the instrument was used outside of a temperature-controlled environment. In this study, board temperature of the HR4000 was automatically recorded for each acquisition for indication of required temperature correction.

Control acquisition software. The Automated Spectrometer Acquisition System (ASAS) has been designed for operation with Ocean Optics CCD array spectroradiometers when measurements are required to be repeated at specific time intervals under variable illumination conditions. The schedule of measurements, for example start, end and interval times between measurements, is set within ASAS software so that measurements run autonomously. Captured data may be analyzed within ASAS; the results are displayed in tabular and graphical formats.

The ASAS program works by automatically determining the acquisition time of the current light conditions for the specified spectral range to reach a user-defined target count level. Between scheduled measurements, the equipment continuously takes acquisitions and estimates the integration time for the next scheduled time.

Within each scheduled acquisition, up to three spectral regions can be chosen to optimize the signal-to-noise ratio within a narrower spectral range than the full spectral capability of the instrument. The maximum count level measured by the HR4000 in the 280–1100 nm solar spectrum is at approximately 530 nm; the signal measured at 400 nm is 20–30% of the maximum value; at 350 nm the signal is less than 10% of maximum value, whereas background is nearly constant across the whole spectral range. If the full spectral range is measured in a single acquisition, data at wavelengths shorter than 400 nm may be subject to low signal-to-noise ratios. Splitting the full instrument spectral range into segments enables optimization of the signal in each spectral region separately while allowing saturation outside the region of interest. The choice of spectral regions may be dictated by the target biomarker, for example 315–400 nm UV-A for studies of ocular damage and 380–600 nm for retinal phototoxicity or melatonin entrainment. Selected individual spectral regions could then be "stitched" together to obtain the complete spectrum. If the spectral ranges of these three regions partly overlap, it also provides a useful control measure.

For this study, the following spectral regions were chosen: 280–400 nm, 380–500 nm and the complete spectral region of the HR4000 spectroradiometer, 280–1100 nm. When saturation is permitted outside the restricted spectral range, charge from saturated pixels may leak into adjacent pixels. This effect is especially critical in measurements of the short wavelength UV range where variations in signal level are high. Well depth is specific to the CCD array spectroradiometer; the HR4000 used in this study has a well depth of 16 383 counts. To avoid saturation in the target spectral region and signal nonlinearity near saturation level, the measurement spectral range was set wider than the spectral range of interest, for example 280–450 nm acquisition boundaries were set for the 280–400 nm spectral region and the target count level was set at 15 000, ~90% of the maximum counts.

The time interval between scheduled measurements can be set from a few seconds to 99 h. The time interval must be greater than the actual time required to capture, read out and save light and background data. The minimum time interval for acquisition of three spectral regions based on the maximum integration time for the HR4000 (10 s) is 3 min. In this study, a time interval of 10 min was set; measurements for future cockpit studies could be taken more frequently, for example for measurements during taking off/landing or fights through fast changing cloud cover.

Data were saved as raw spectral data and, if selected, as spectral irradiance and effective spectral irradiance weighted with a specific action spectrum, providing that the instrument was calibrated for spectral irradiance and that background measurements were available. Built-in spectral weighting could be chosen from UV hazard spectral weighting function $S(\lambda)$ (5,20), Erythema spectral weighting function (19), Blue Light hazard spectral weighting function $B(\lambda)$ (6), Retinal Thermal hazard spectral weighting function $R(\lambda)$ (6) and luminous efficiency weighting $V(\lambda)$ (21). For each measurement, the saved data file contains the raw signals for light and dark signals, the calibration, un-weighted and, if spectral weighting is chosen, the effective irradiance. Results are also displayed graphically.

RESULTS AND DISCUSSION

The automated measurement system was deployed during a number of aeroplane and helicopter flights. The sample data presented were taken from a flight on 1 March 2013 from Gatwick (51°N, 0.19°W) to Alicante (38°N, 0.56°W) on an Airbus A321.

Stitching UV spectral region R3 and the whole spectral range R1 showed good overlap and overall stitching was not required for the majority of timed acquisitions. The board temperature of the HR4000 during this flight corresponded to the variation in ambient temperature within 22–29°C where sensitivity change is relatively small (2–3%) and temperature correction was not applied for this flight data.

At cruise altitude, UV-A irradiance measured at a fixed position on the aircraft windscreen increased by factor of almost 50 compared with the measurement at ground level at departure in the morning, and by a factor of 6–7 compared with ground level at the destination in the early afternoon, see Fig. 3a. Erythema-weighted irradiance varied from negligible (<<1 mWm^{-2}) at ground level on departure to 16–20 mWm^{-2} at cruise altitude and 4–5 mWm^{-2} at ground level at the destination.

Similarly, Blue Light irradiance at cruise altitude (Fig. 3b) reached 60 Wm^{-2} and increased by a factor of 50–60 compared with the ground level at departure and by a factor of 7–8 at destination. While all measured parameters, for example illuminance, UV-A, erythema and Blue–Light-weighted irradiances, varied considerably during flight, UV-A, erythema and Blue–Light-weighted irradiances closely followed the illuminance; the ratios of these values with respect to the illuminance, known as hazard ratios and expressed in Wlm^{-1} (18,19), were substantially

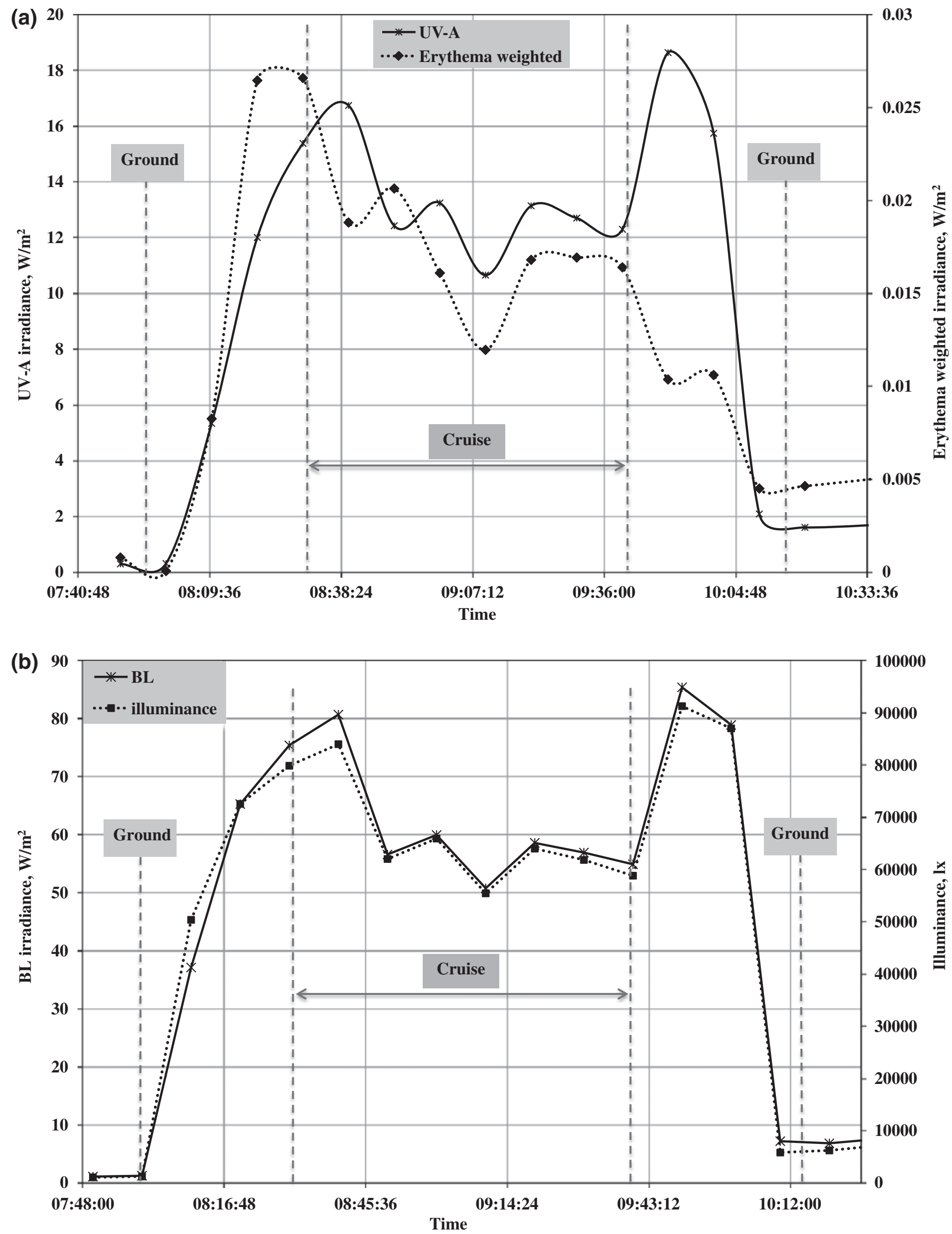


Figure 3. Variations in UV-A and erythema-weighted irradiance (a); Blue Light irradiance and illuminance (b) during flight.

constant at cruise altitude and were very similar at ground level on departure and at the destination as shown in Fig. 4. The larger difference in erythema hazard ratio at ground level on departure and at the destination needs further investigation; it may be attributed to the lower latitude of Alicante (38°N) compared with Gatwick (51°N).

Hazard ratios shown in Fig. 4 and illuminance measured at pilot's eye level were used to estimate UV-A ocular exposure presented in Fig. 5.

The UV-A exposure for the duration of this flight measured at a fixed position on the aircraft windscreen exceeded 97 kJm^{-2}. Ocular UV-A exposure of pilots varied between approximately 20 kJm^{-2} (looking down) and 26 kJm^{-2} (looking ahead).

The ocular exposure of pilots during this flight could have exceeded the ICNIRP guidance of 10 kJm^{-2} for a maximum 8 h UV-A exposure if appropriate eye protection was not used. Use of sunglasses and visors, therefore, is very important and should reduce ocular exposure.

Erythema-weighted exposure in this flight reached 1.4 SEDs. Some studies (7,22,23) have shown that indoor workers, as with most of the population, typically experience about 300 SEDs per year from solar exposure, mostly from weekends and holidays. Outdoor workers at the same latitudes may receive in excess of 1000 SEDs per year.

The measured erythema-weighted exposure during this flight was significantly higher than the level of 0.019 MED h^{-1} previously reported by Diffey and Roscoe (8) which may be due to contribution of high level of UV-A in the current measurements which was not possible to measure in the previous study and/or a difference in the UV transmission of aircraft windscreens. This

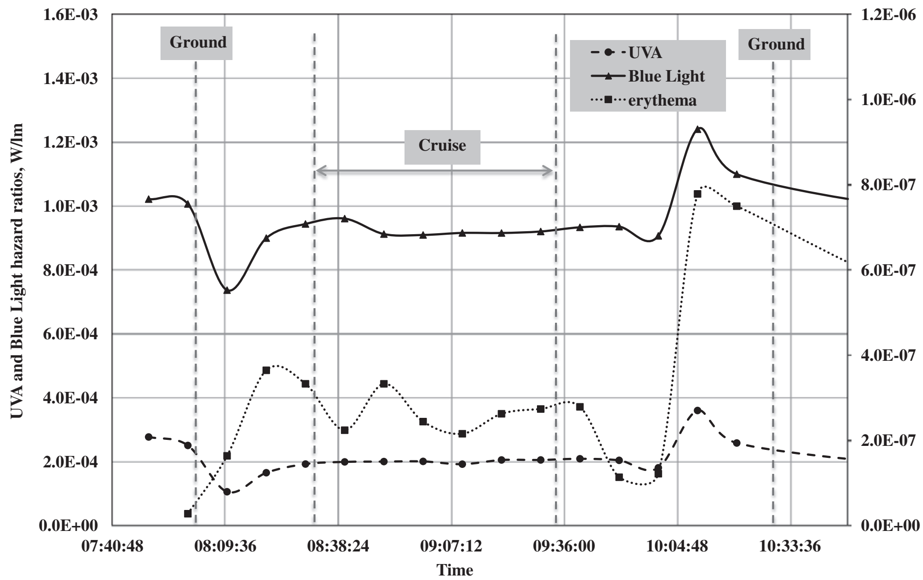


Figure 4. Variation of hazard ratios during flight.

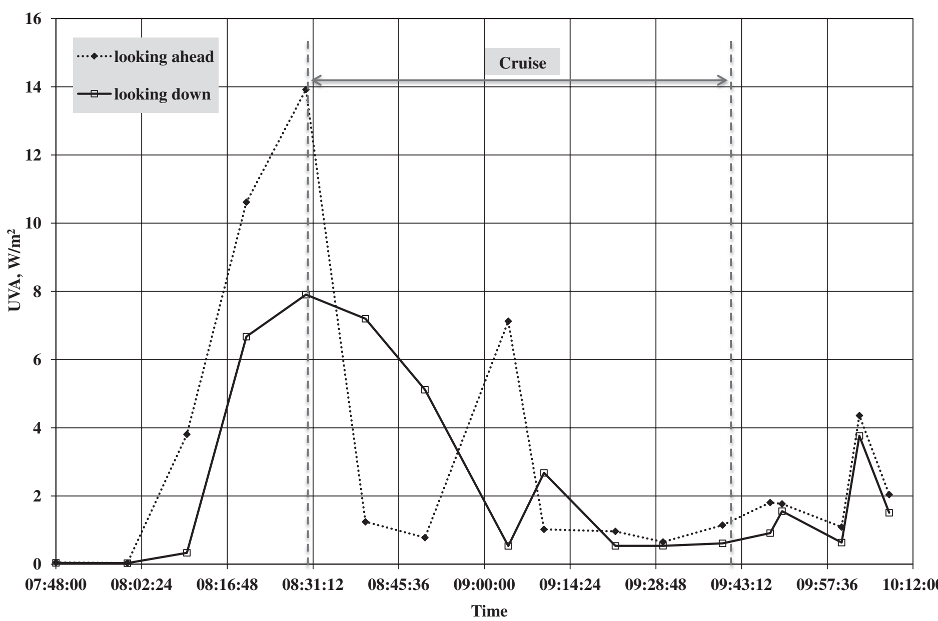


Figure 5. Estimated UV-A irradiance at pilot's eye level during flight.

difference and the analysis of the higher erythema dose requires further investigation.

CONCLUSIONS

Methods for the assessment of personal UVR exposures of commercial aircraft pilots and instrumentations for automated time-stamped spectral measurements were developed and tested in a number of aircraft and helicopter flights during 2012–2013, shown here on an example of a Gatwick-Alicante flight.

The method combines the capture of automated spectral data from a fixed position just behind the front windshield with unobtrusive manual measurements of illuminance at the pilot's eye level from the jump seat during flight. The spectral measurements were collected using bespoke automation software. The software enabled advanced acquisition techniques of automated dark signal capture and multiband integration control optimizing the dynamic performance of the spectrometer over the full spectral range.

The data presented show that, despite the ergonomic constraints of the flight deck and the importance of maintaining flight safety, time-stamped spectral measurements can be successfully and accurately gathered throughout flight.

Comparison of ground and altitude measurements over a series of flights will enable a more detailed evaluation of the effects of altitude and irradiance levels. In addition, with continuous data acquisition throughout flight, the occupational UVR and Blue Light hazard dose to the pilot can be calculated. These data could also be used for analysis of circadian disruption.

Using this equipment and measurement protocol on various aircraft on differing routes at different times of the year will enable the variance of exposure to be ascertained and to identify those flights where exposure is likely to be greatest. Further knowledge of the eye protection habits of professional pilots will help to identify whether current practices are likely to offer the pilot adequate protection from ocular damage. In addition, these data will enable evidence-based guidance on optimum ocular solar protection for pilots when choosing sunglasses.

Acknowledgements—The authors thank Professor Bruce Evans, Dr Martin Benwell and Dr John O'Hagan for continuing support and valuable advice. The assistance of Luke Price with the validation of acquisition software and valuable contributions to this article is gratefully acknowledged. The study of the temperature dependence of the HR4000 performance was funded by Researcher Excellence Grant within EMRP ENV03 "Traceability for surface spectral solar ultraviolet radiation". The EMRP is jointly funded by the EMRP participating countries and the European Union.

REFERENCES

1. Blumthaler, M., W. Ambach and R. Ellinger (1997) Increase in solar UV radiation with altitude. *J. Photochem. Photobiol., B* **39**, 130–134.
2. Chorley, A., B. Evans and M. Benwell (2011) Civilian pilot exposure to ultraviolet and blue light and pilot use of sunglasses. *Aviat. Space Environ. Med.* **82**(9), 895–900.
3. Chorley, A., B. Evans and M. Benwell (2013) Solar eye protection habits of civilian professional pilots. *Med Aeronaut Spat.* **54**(202), 61–67.
4. Hammer, G. P., M. Blettner and H. Zeeb (2009) Epidemiological studies of cancer in aircrew. *Radiat. Prot. Dosimetry* **136**, 232–239.
5. ICNIRP (2004) Guidelines on limits of exposure to ultraviolet radiation of wavelengths between 180 nm, 400 nm (Incoherent Optical Radiation). *Health Phys.*, **87**(2), 171–186.
6. ICNIRP (2013) Guidelines on limits of exposure to incoherent visible, infrared radiation. *Health Phys.*, **105**(1), 74–96.
7. International Commission on Non-Ionizing Radiation Protection Statement (2010) On Protection of workers against ultraviolet radiation. *Health Phys.*, **99**(1), 66–87.
8. Diffey, B. L. and A. H. Roscoe (1990) Exposure to solar ultraviolet radiation in flight. *Aviat. Space Environ. Med.* **61**, 1032–1035.
9. Roscoe, A. H. and B. L. Diffey (1994) A preliminary study of blue light on an aircraft flight deck. *Health Phys.* **66**, 565–567.
10. International Commission on Illumination (1992) Personal dosimetry of UV radiation. Publication No CIE 98. International Commission on Illumination, Wein, Austria.
11. Coleman, A., R. Sarkany and S. Walker (2008) Clinical ultraviolet dosimetry with a CCD monochromator array spectroradiometer. *Phys. Med. Biol.* **53**(18), 5239–5255.
12. Kreuter, A. and M. Blumthaler (2009) Stray light correction for solar measurements using array spectrometers. *Rev. Sci. Instrum.* **80**(9), 096–108.
13. Ylianttila, L., R. Visuri, L. Huurto and K. Jokela (2005) Evaluation of a single-monochromator diode array spectroradiometer for sunbed UV-radiation measurements. *Photochem. Photobiol.* **81**(2), 333–341.
14. Nilsen, L. T. N., T. N. Aalerud, M. Hannevika and B. M. Veierød (2011) UVB and UVA irradiances from indoor tanning devices. *Photochem. Photobiol. Sci.* **10**, 1129–1136.
15. Seckmeyer, G., A. Bais, M. Blumthaler, S. Drüke, P. Kiedron, K. Lantz, R. McKenzie and S. Riechelmann (2010) Instruments to measure solar ultraviolet radiation Part 4: Array Spectroradiometers. WMO/GAW No.191, World Meteorological Organization, Geneva.
16. Salim, S., N. Fox, W. Hartree, E. Woolliams, T. Sun and K. Grattan (2011) Temperature and nonlinearity corrections for a photodiode array spectrometer used in the field. *Appl. Opt.* **50**(6), 866–875.
17. Blumthaler, M., J. Gröbner, L. Egli and S. Nevas (2013) A guide to measuring solar UV spectra using array spectroradiometers. *Proc. AIP Conference* **1531**, 805. doi:10.1063/1.4804892.
18. Sliney, D. and M. L. Wolbarsht (1980) *Safety with Lasers and Other Optical Sources: A Comprehensive Handbook*. Plenum Press, New York.
19. Bonner, R., M. Khazova and J. B. O'Hagan (2012) Assessment of personal exposures to optical radiation in large entertainment venues. *Radiat. Prot. Dosimetry.* **149**(3), 225–237.
20. McKinlay, A. F. and B. L. Diffey (1987) A reference action spectrum for ultraviolet induced erythema in human skin. *CIE* **6**(1), 17–22.
21. CIE S 010/E (2004) *Photometry - The CIE system of Physical Photometry*. International Commission on Illumination, Vienna, Austria.
22. Gies, H. P., C. R. Roy and G. Elliott (1992) Ultraviolet radiation protection factors for personal protection in both occupational and recreational situations. *Radiat. Protect. Aust.* **10**, 59–66.
23. Gies, H. P., C. R. Roy, S. Toomey, R. MacLenan and M. Watson (1995) Solar UVR exposure of three groups of outdoor workers on the sunshine coast, Queensland. *Photochem. Photobiol. Sci.* **62**, 1015–1021.

Appendix D: Information sheet

The occupational use of eye protection by commercial pilots

Dear

You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what is involved. Please take time to read the following information and discuss it with others if you wish. Feel free to ask me if there is anything that is not clear or you would like more information. Take time to decide whether you wish to take part.

Thank you for reading this.

It is known that long term exposure to short wavelength light including ultraviolet can have detrimental effects to the eyes. There is a greater risk of eye conditions such as cataract and macular degeneration. Eye protection, such as the use of sunglasses in the cockpit, should block potentially harmful light. However, it is not known the frequency or type of eye protection used by pilots. I would like to conduct a one-to-one interview with you to help me establish, from your own experience and from observing other pilots, the types and diversity of strategies used by pilots to protect their eyes from sunlight and glare.

Be assured that participation is voluntary and any information given regarding your own eye protection habits will not affect your medical certification. Although the Authority has issued guidelines for the selection of pilot sunglasses, it is not proven that these are appropriate. Your interview forms part of a larger research project. I plan to use information that you give me to develop a questionnaire which we hope a large number of commercial pilots will complete.

Further parts of the research project include the measurement of cockpit light levels at altitude and measurement of the effectiveness of a range of sunglasses at these light levels. This research will hopefully lead to a much better understanding of the occupational light levels in aviation and targeted advice on sunglass selection to pilots.

Your interview will be audio recorded so that all appropriate information that you give can be used. No personal identifying information will be recorded and the recordings will be deleted once all the information has been transcribed. I will keep a record of who has been interviewed; however, this will be stored separately and will not be shared with others. All of the information you give me will be stored in accordance with the Data Protection Act (1998).

For the purposes of a future part of the research, you may be asked if you would be willing to donate your current aviation sunglasses for testing and measurement. In this scenario, new replacement sunglasses of the same type would be provided to you.

The Authority is sponsoring this research and it is likely that the results will be published as a CAA paper sometime around 2013. The research has ethical approval from the Institute of Optometry and the Faculty of Health and Social Care Ethics Committee at London South Bank University.

In the event of dissatisfaction with the conduct of your interview, feel free to contact my supervisor, Professor Bruce Evans, Director of Research at The Institute of Optometry, 56-62 Newington Causeway, London SE1 6DS (bruce.evans@virgin.net).

I hope that you will consider participating. If you do decide to take part, you will be given this information sheet to keep and asked to sign a consent form. If you decide to take part, you are still free to withdraw at any time. Again, if you have any further questions, I would be happy to discuss these with you.

Thank you

Adrian Chorley

Adrian.chorley@caa.co.uk
01293-573637

Appendix E: Consent form

The occupational use of eye protection by commercial pilots

- I have read the attached information sheet on the research in which I have been asked to participate and have been given a copy to keep. I have had the opportunity to discuss the details and ask questions about this information.
- The investigator has explained the nature and the purpose of the research and I believe that I understand what is being proposed.
- I understand that my personal involvement and my particular data from this study will remain strictly confidential.
- I have been informed that the interview will be audio recorded, what the data collected in this investigation will be used for, to whom it will be disclosed, and how long it will be retained.
- I understand that I am free to withdraw from the study at any time, without giving a reason for withdrawing.
- I hereby fully and freely consent to participate in the study.

Participant's Name: (Block Capitals) ……………………………..

Participant's Signature: ……………………………..

Date: ……………………………..

As the investigator responsible for this investigation, I confirm that I have explained to the participant named above, the nature and purpose of the research to be undertaken.

Investigator's Name: ADRIAN CHORLEY

Investigator's Signature: …..……………………….

Date: …..……………………….

Appendix F: Questionnaire information sheet

Dear aviator

It is known that long term exposure to short wavelength (energetic blue) light and ultraviolet can have detrimental effects to the eyes. Over time, there is a greater risk of eye conditions such as cataract and macular degeneration following exposure.

Eye protection, such as the use of sunglasses in the cockpit, should help to block potentially harmful light. However, the type of eye protection used and the frequency of its use by pilots is currently unknown. Additionally, the light levels at altitude, once filtered by the aircraft windscreen are not fully understood.

As a commercial or airline pilot, you are being invited to take part in a research study and we need your help! Please take time to read the following information and decide whether you wish to take part. The aim of this research is to develop a clear picture of the risk to professional pilots of long term exposure to short wavelengths and to provide evidence based guidance as to the optimum eye protection for use within the cockpit.

This survey should take around 5-10 minutes to complete. The researchers are looking to understand overall trends and averages, not individual responses. No identifying information such as name, email address or CAA reference number will be requested.

More details about the study.

- The information being collected in this survey is being used for research purposes only. The research team are committed to protecting your privacy and security on line.
- By participating in this survey, you are consenting to having your responses and information about your eye protection habits used by the Institute of Optometry, London South Bank University and the UK Civil Aviation Authority as part of the research on pilot eye protection.
- Research results from this survey should be published in a scientific journal and as a CAA paper after 2013. The research has ethical approval from the Institute of Optometry and the London South Bank University Research Ethics Committees.

- Participation is voluntary. All information will remain confidential and results anonymous and will be stored in accordance with the Data Protection Act (1998). The results will be retained for 10 years after completion of the project in accordance with Medical Research Council guidance.
- If during the survey you would like to withdraw and not have your answers used, please email the researcher at the address below.
- If you have any questions regarding the survey, please contact Adrian Chorley on 01293-573637 or adrianchorley1@aol.co.uk. If you have any concerns about this survey please contact Professor Bruce Evans, Director of Research at The Institute of Optometry, 56-62 Newington Causeway, London SE1 6DS (bjwe@bruce-evans.co.uk).

We very much appreciate your taking the time to complete this survey. Thank you.

Appendix G: Equipment information and risk assessment

1. Introduction

The Ocean Optics HR4000 high resolution spectrometer is a device for capturing light spectra data. The instrument measures light and does not emit any light or other radiation or radio waves.
The serial number for this equipment is: HR4C1877

2. The equipment
   a) Ocean Optics Spectrometer HR4000

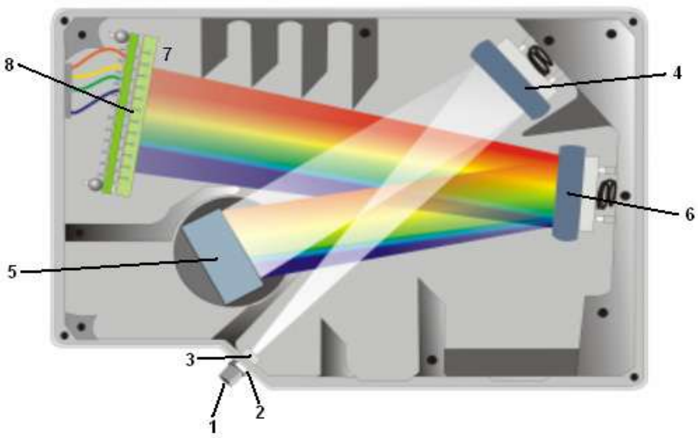
External

The HR4000 is a sealed unit. The casing measures 15cm x 10.5cm x 4.5cm. The weight of the HR4000 is 570 g.

Internal

The USB4000 Spectrometer connects to a computer via the USB port. When connected through a USB 2.0 or 1.1, the spectrometer draws power from the host computer, eliminating the need for an external power supply. The HR4000 will be controlled by the LabView automation software that operates on Windows operating systems.

Below is a diagram of how light moves through the optical bench of an HR4000 Spectrometer. The optical bench has no moving parts that can wear or break; all the components are fixed in place at the time of manufacture. The table below lists internal components of the spectrometer.



Item	Name	Description
1	SMA Connector	Secures the input fiber to the spectrometer. Light from the input fiber enters the optical bench through this connector.
2	Slit	A dark piece of material containing a rectangular aperture, which is mounted directly behind the SMA Connector. The size of the aperture regulates the amount of light that enters the optical bench and controls spectral resolution. Only Ocean Optics technicians can change the Slit.
3	Filter	Restricts optical radiation to pre-determined wavelength regions. Light passes through the Filter before entering the optical bench. Both bandpass and longpass filters are available to restrict radiation to certain wavelength regions. Only Ocean Optics technicians can change the Filter.
4	Collimating Mirror	Focuses light entering the optical bench towards the Grating of the spectrometer. Light enters the spectrometer, passes through the SMA Connector, Slit, and Filter, and then reflects off the Collimating Mirror onto the Grating.
5	Grating	Diffracts light from the Collimating Mirror and directs the diffracted light onto the Focusing Mirror. Gratings are available in different groove densities, allowing you to specify wavelength coverage and resolution in the spectrometer. Only Ocean Optics technicians can change the Grating.
6	Focusing Mirror	Receives light reflected from the Grating and focuses the light onto the CCD Detector or L2 Detector Collection Lens (depending on the spectrometer configuration).
7	L2 Detector Collection Lens	An optional component that attaches to the CCD Detector. It focuses light from a tall slit onto the shorter CCD Detector elements. Only Ocean Optics technicians can add or remove the L2 Detection Collection Lens.
8	CCD Detector	Collects the light received from the Focusing Mirror or L2 Detector

	(UV or VIS)	Collection Lens and converts the optical signal to a digital signal. Each pixel on the CCD Detector responds to the wavelength of light that strikes it, creating a digital response. The spectrometer then transmits the digital signal to the OOIBase32 application.

b) 2 metre long Ocean Optics 600µm diameter optical fibre in protective metal jacket.

c) Ocean Optics CC-3-UV diffuser (19 mm length, 6 mm diameter)

d) Ocean Optics shutter (14 cm s 5cm x 5cm, weight 600g)

The INLINE-TTL-S is TTL-driven shutter which allows blocking the light path without disturbing the experiment. The INLINE-TTL is driven by a small board that is powered with 12VDC with a TTL input. Included is a cable for interfacing to a spectrometer. During the cockpit studies, the shutter will be powered by a YSN-12680 12V DC battery.

3. Description of Operation

Light data is captured through the CC-3-UV diffuser attached the fibre optic cable which is connected to a TTL-S shutter which is turn connected to both the HR4000 spectrometer and a notebook or handheld PC (by PIN 15 connection). The shutter will be operated by the automation software.

The HR4000 Spectrometer also connects to the notebook or handheld PC via USB port. When connected to the USB port of a computer, the HR4000 draws power from the host computer, eliminating the need for an external power supply. The computer to which the spectrometer is connected is an Asus R2E handheld palmtop computer (23.5 cm x 13.5 cm x 3 cm, weight 830g) with Microsoft Vista operating platform. The computer will have installed automation software to drive both the spectrometer and the shutter. The computer is not connected in any way to the aircraft systems and is run from a battery pack.

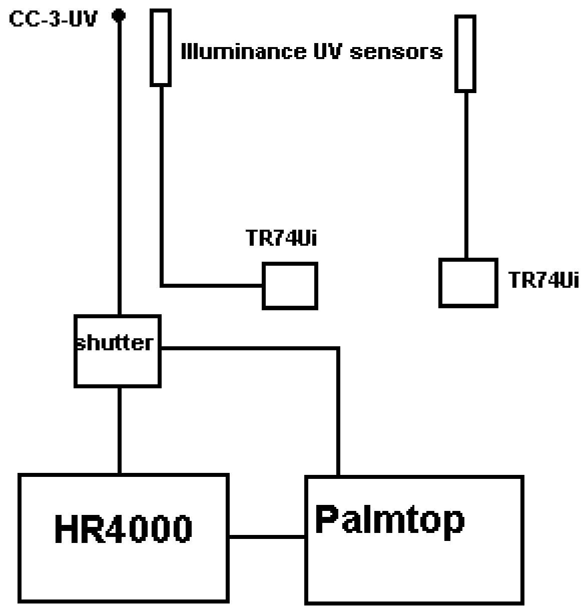
Additionally, illuminance recordings will be taken using 2 TandD TR74Ui with 2 illuminance UV sensors. (Image shows equipment with 1 illuminance UV sensor and 1 temperature/humidity sensor). The unit requires one AA alkaline battery and measures 5.5cm x 7.8cm x 1.8cm, weight 62g.

4. Intended locations for equipment (aircraft types)

Light data is to be collected within the cockpit at altitude. The light spectra and intensity is collected at the position of the collecting head. The spectrometer and associated handheld PC can be positioned up to 2 metres away.

The collecting probe and one illuminance meter are to be positioned in a fore position, ideally at the front window, out of line of sight and vision of the pilot. The spectrometer, TR74Ui unit, shutter and palmtop PC can be secured up to 2 metres away. They are linked by a cable and no wireless or other radio signals are generated. The spectrometer will be programmed to take a series of automated spectral readings during flight and will not be required to be assessed by the researcher. The second illuminance meter will be hand held by the researcher collecting data who will be present in the jump seat. A series of illuminance measurements will be taken during flight with the probe positioned facing forward between the captain and first officer at eye level.

A diagrammatic summary of the set up is shown below.



5. Hazard Assessment
   a) Temperature and Altitude

The operating temperature range of the spectrometer is –10˚ to +50˚ C. The operating temperature range of the illuminance UV recorder is –10˚ to +60˚ C. Altitude will not impact upon the equipment's performance.

   b) Temperature Variation

Large cyclic temperature changes to the spectrometer may affect the instrument's performance therefore, care must be taken not to allow the unit to be exposed to direct sunlight. The researcher collecting data will assess if large temperature variations to the unit may have affected the unit calibration and will instigate a calibration check, if appropriate, after flight.

   c) Humidity

Operating limits stated by the manufacturers are 0 to 90% humidity.

   d) Operational Shocks and Crash Safety

Shocks and are not anticipated to affect the performance of the spectrometer. However, significant shocks to the unit will necessitate a calibration recheck of the unit after flight. The researcher collecting data will assess when a calibration check is required. The illuminance UV recorder should not be affected by shocks. However, significant shocks causing damage to the unit will necessitate a new unit to be purchased.

   e) Vibration

The construction of the spectrometer is such that, as the unit has no moving parts, vibration is not anticipated to affect the unit. However, significant vibration to the unit will trigger a calibration recheck of the unit after flight. The researcher collecting data will assess when a calibration check is required. The illuminance UV recorder should not be affected by vibration.

f) Explosion Proofness

It is not anticipated that the spectrometer, illuminance UV recorder and associated PC will come into contact with flammable liquids or gases.

g) Waterproofness

It is not anticipated that the spectrometer and associated PC, illuminance UV recorder will come into contact with water.

h) Fluids Susceptibility

It is not anticipated that the spectrometer, illuminance UV recorder and associated PC will be installed in an environment where fluid spills are likely. Spills of hot or cold drinks might be possible on the flight deck. In this case, the unit casing should prevent fluid penetration. Any concerns by the researcher of fluid ingress to the unit would warrant a calibration check after flight. Fluid penetration into the illuminance UV recorder causing non-function would necessitate purchase of a new unit.

i) Sand and Dust

The spectrometer, illuminance UV recorder and associated PC will be on the flight deck for short periods of time. The units' casing will prevent dust ingress

j) Fungus Resistance

Not applicable by virtue of the location/time span of the installation

k) Salt Spray

Not applicable by virtue of the location/time span of the installation

l) Magnetic Effect

Not applicable by virtue of the location/time span of the installation

m) Power Input

The Asus PC can run from a mains supply, through a 12V charger or from the PC's battery pack. A fully charged battery pack will provide a few hours of working power and the actual figure will vary depending on use of power saving features, system memory size and PC usage. A spare battery pack is available and would be fully charged before flight. The spectrometer draws power from the PC and does not require a dedicated power supply.

The shutter will be powered by a YSN-12680 12V DC battery and TR74Ui by one 1.5V AA alkaline battery.

n) Voltage Spike

The equipment will not be plugged in to the aircraft power supply

o) Lightning Induced Transient Susceptibility

This is not applicable by virtue of the location of the spectrometer, illuminance UV recorder and associated PC within the flight deck

p) Lightning Direct Effects

This is not applicable by virtue of the location of the spectrometer, illuminance UV recorder and associated PC within the flight deck

q) Icing

This is not applicable by virtue of the location of the spectrometer, illuminance UV recorder and associated PC within the flight deck

Appendix H: CAA letter of endorsement

Safety Regulation Group
Medical Department

Civil Aviation Authority

To: Head of Airline Flight Operations

December 2011

Cockpit light spectra study

The Civil Aviation Authority's Medical Department has initiated a research study, to assess the levels of non-ionising radiation (particularly ultraviolet and visible light) within the cockpit at altitude. The study will be conducted by Mr Adrian Chorley, the Authority's Optometrist Principal, and involves measurement of the light spectra using a small spectrometer.

The aim of the research is to quantify light levels at altitude and then to provide evidence-based guidance on appropriate eye protection for pilots. The Authority supports this research and has provided funding for the equipment.

The equipment to be used in the study falls within the Class 1 EFB or portable electronic device category, and as such would not require airworthiness approval. It is light, portable, collects data passively, emits no radiation and is independently powered. Preliminary assessment (ideally in a simulator) would be required to ensure that the equipment could be located and used without affecting the aircraft operation or flight safety. Further information is given in the enclosed technical document.

We hope to carry out this research on a number of aircraft types and on both shorthaul and longhaul operations. We are seeking participation from a number of UK airlines and would be most grateful for your support in conducting this research. There would be no cost to the airline, other than any indirect costs associated with the preliminary assessment to determine the safe location and use of the equipment and in the carriage of the researcher on the flight deck during the data collection phase.

If you require further information, please contact Adrian Chorley directly on 0044 (0)1293 573637 or adrian.chorley@caa.co.uk

Yours sincerely

Sally Evans

Dr Sally Evans
Chief Medical Officer

Captain Bob Jones
Head of Flight Operations

Civil Aviation Authority
GW Aviation House Gatwick Airport South West Sussex England RH6 0YR
Telephone 01293 573700 Fax 01293 573995 www.caa.co.uk medicalweb@caa.co.uk

Appendix I: Research ethics approval letter from London South Bank University

Direct line: 020-7815 6024
E-mail: harrism7@lsbu.ac.uk

Ref: UREC 1033

Mr A. Chorley.
Civil Aviation Authority
Medical Department,
Aviation House,
Gatwick Airport South,
W. Sussex
RH6 0YR

6 December 2010

Dear Adrian,

Research proposal: *Occupational ultraviolet and blue light ocular protection in pilots*

Thank you for submitting this application and for your response to the points raised in review. I am pleased to tell you that ethical approval has been given by Chair's action on behalf of the University Research Ethics Committee.

I enclose a copy of this letter for the Institute of Optometry Research Ethics Committee.

I wish you every success with your research.

Yours sincerely,

Mark Harris
Deputy University Secretary
Secretary, LSBU Research Ethics Committee

c.c. Professor Joan Curzio, Acting, Chair, LSBU Research Ethics Committee

Appendix J: Research ethics approval letter from the Institute of Optometry

Ronald Rabbetts, MSc, FCOptom, SMSA, DCLP
31 Warblington Street
PORTSMOUTH, PO1 2ET

Phone: 023 92816571
Email: ronald.rabbetts@virgin.net

12 January 2011

Reference:

Application from Mr Adrian Chorley for research for his Doctorate of Optometry:

Occupational ultraviolet light and blue light ocular protection in pilots

My colleagues and I on the Institute of Optometry's Research and Ethical Committee have read Adrian Chorley's LSBU Research application. Several suggestions were made from an optometric point of view. Mr Chorley has either dealt with these in the revised application documents or replied to our concerns in his reply document.

On behalf of the Institute of Optometry Research and Ethical Committee, I am happy to confirm our agreement on the revised documents and our approval for the study to proceed.

Yours sincerely

Ronald Rabbetts

Ronald Rabbetts,
Chairman, Institute of Optometry's Research and Ethical Committee

Appendix K: Interview coding and categorisation

Topics covered within Interview Questions:

Length of time licence held

Total flight time logged

Aircraft type(s) flown

Requirement on medical certificate for spectacles to be worn

- Tinted prescription specs
    - Tint type: Colour, uniform/graduated/photochromatic/polarised
    - Age and condition
    - Fitted professionally or not
- Plano sunglasses used on top of own glasses
- Contact lenses used
    - UV block on contact lenses

Sunglasses used for aviation

- Make and type: Colour, uniform/graduated/photochromatic/polarised
- Age and condition
    - Fitted professionally or not
- Considerations at selection and purchase (e.g., cost/comfort/other)

Previous sunglasses used for aviation

- Description of type
- Details of how these compared with current sunglasses

More than one pair of sunglasses used for aviation

- What tasks are each set of sunglasses used for

Requirement on medical certificate for spectacles to be carried (reading glasses)

- Affect of this to using sunglasses

Awareness and use of CAA guidance on sunglass selection

Description of any aircraft sun protection systems

- When used and issues with use

Other strategies used during flight

- Type, when used and issues with use

Any circumstances where glare (discomfort or disability) more apparent

Issues flying towards direct sunlight

Any circumstances where there are issues with interpreting flight information

Experience with sunlight management on different aircraft types

- How it may be different and if different protection practices used

Observed eye protection practices in other pilots

- Description of any practices that it is felt may affect flight safety

Eye health concerns

Other comments with regard to sunlight & sunglasses in the cockpit

Quantitative data entered onto Excel spreadsheet:

Length of time licence held	Requirement on medical for spectacles to be worn / carried
Total flight time logged	Details of prescription / non-prescription sunglasses – when used
Aircraft type(s) flown	CAA guidance used
Other strategies used	Sun protection on different aircraft types
Symptoms of glare	Presence of health concerns
Other observed practices	

Initial interview category themes:

1) Sun	6) Previous sunglass experience
2) Sunlight & flight information	7) Strategies
3) When sunglasses used	8) Observed practices in other pilots
4) Comfort and choice of sunglasses	9) Experience on different aircraft
5) Sunglass tint	10) Eye health

Final coding categorisation:

The visual environment

External - where sunlight most of an issue and any symptoms arising

Internal - Description of sun protection systems, instrument lighting

Additional consideration for helicopter pilots

Coping strategies

Sunglasses – type, when worn, compatibility with spectacle use, comfort issues

Standard aircraft sun protection systems - difference between aircraft type, seen as primary aid for controlling sunlight levels

Adaptation to standard aircraft sun protection systems – reported only in airline operations, items used for additional solar protection

Other practices – hats, adjusting seat, using hand in front of eyes, squinting, use of helmet with visor, which strategies are more prevalent in different flight operations

Observed practices in other pilots – range of sunglass use observed, clip-ons, newspapers to block sunlight

Eye Health concerns – yes, no, non eye-related health concerns

Appendix L: Questionnaire

Eye protection and professional pilots

1. Eye protection and professional pilots

Dear aviator

It is known that long term exposure to short wavelength (energetic blue) light and ultraviolet can have detrimental effects to the eyes. Over time, there is a greater risk of eye conditions such as cataract and macular degeneration following exposure. Eye protection, such as the use of sunglasses in the cockpit, should help to block potentially harmful light. However, the type of eye protection used and the frequency of its use by pilots is currently unknown. Additionally, the light levels at altitude, once filtered by the aircraft windscreen are not fully understood.

As a professional pilot, you are being invited to take part in a research study and we need your help! Please take time to read the following information and decide whether you wish to take part. The aim of this research is to develop a clear picture of the risk to professional pilots of long term exposure to short wavelengths and to provide evidence based guidance as to the optimum eye protection for use within the cockpit.

This survey should take around 5-10 minutes to complete. The researchers are looking to understand overall trends and averages, not individual responses. No identifying information such as name, email address or CAA reference number will be requested.

More details about the study.

• The information being collected in this survey is being used for research purposes only. The research team are committed to protecting your privacy and security on line.
• By participating in this survey, you are consenting to having your responses and information about your eye protection habits used by the Institute of Optometry, London South Bank University and the UK Civil Aviation Authority as part of the research on pilot eye protection.
• Research results from this survey should be published in a scientific journal and as a CAA paper after 2013. The research has ethical approval from the Institute of Optometry and the London South Bank University Research Ethics Committees.
• Participation is voluntary. All information will remain confidential and results anonymous and will be stored in accordance with the Data Protection Act (1998). The results will be retained for 10 years after completion of the project in accordance with Medical Research Council guidance.
• If during the survey you would like to withdraw and not have your answers used, please email the researcher at the address below.
• If you have any questions regarding the survey, please contact Adrian Chorley on 01293-573637 or adrianchorley1@aol.co.uk. If you have any concerns about this survey please contact Professor Bruce Evans, Director of Research at The Institute of Optometry, 56-62 Newington Causeway, London SE1 6DS (bjwe@bruce-evans.co.uk).

We very much appreciate your taking the time to complete this survey. Thank you.

***How many years have you been a professional pilot?**

Eye protection and professional pilots

***What is your current flight time logged?**

- ◯ <1,000 hours
- ◯ 1,000 - 2,500 hours
- ◯ 2,500 - 5,000 hours
- ◯ 5,000 - 7,500 hours
- ◯ 7,500 - 10,000 hours
- ◯ 10,000 - 12,500 hours
- ◯ 12,500 - 15,000 hours
- ◯ >15,000 hours

***Which category best describes the main type of flying that you undertake?**

- ◯ Aeroplane airline transport long haul
- ◯ Aeroplane airline transport short haul
- ◯ Aeroplane cargo
- ◯ Aeroplane business jet
- ◯ Aeroplane charter
- ◯ Aeroplane aerial work
- ◯ Aeroplane instructor
- ◯ Helicopter off-shore
- ◯ Helicopter charter
- ◯ Helicopter police/air ambulance
- ◯ Helicopter aerial work
- ◯ Helicopter instructor
- ◯ Other

Other (please specify)

____

***Approximately how many hours have you flown within the last year?**

____

***What other categories of professional flying have you previously undertaken? (Tick all that apply)**

- ☐ No other categories
- ☐ Aeroplane airline transport long haul
- ☐ Aeroplane airline transport short haul
- ☐ Aeroplane cargo
- ☐ Aeroplane business jet
- ☐ Aeroplane charter
- ☐ Aeroplane aerial work
- ☐ Aeroplane instructor
- ☐ Aeroplane military
- ☐ Helicopter off-shore
- ☐ Helicopter charter
- ☐ Helicopter police/air ambulance
- ☐ Helicopter aerial work
- ☐ Helicopter instructor
- ☐ Helicopter military
- ☐ Other

Other (please specify)

____

Eye protection and professional pilots

*** On your medical certificate, is there a requirement for corrective lenses to be worn and spare correcting spectacles to be carried (VDL limitation)?**

- Yes
- No

2. Eye protection and professional pilots

*** How long has the spectacle requirement been present on your medical certificate?**

- Within last 5 years
- 5-10 years
- >10 years
- I have always had this requirement on my medical certificate

*** Do you use clip-on shades onto your prescription glasses?**

- Yes
- No

*** Do you wear contact lenses in flight?**

- Yes
- No

3. Eye protection and professional pilots

*** Do your contact lenses have a UV block?**

- Yes
- No
- Don't know

4. Eye protection and professional pilots

*** Do you ever wear sunglasses in the cockpit environment?**

- Yes
- No

5. Eye protection and professional pilots

Eye protection and professional pilots

What, if any, are the reasons that you do not wear sunglasses in flight? Tick all that apply

- [ ] Aircraft has adequate protection offered with visors
- [ ] I forget to carry them with me
- [ ] I wear clear prescription glasses instead
- [ ] Sunglasses too expensive
- [ ] Sunglasses uncomfortable
- [ ] Sunlight doesn't bother me
- [ ] Too much hassle to put on during flight
- [ ] Other strategies used (please give details)

6. Eye protection and professional pilots

***Overall, what percentage of daytime flights would you wear sunglasses?**

○ <10% ○ 10-30% ○ 30-50% ○ 50-70% ○ 70-90% ○ >90%

***Do you use more than one pair of sunglasses within a flight?**

○ Yes

○ No

***Thinking about the sunglasses that you use most frequently. When would you normally wear them?**

	Never	Rarely	Sometimes	Usually	Always
Walkaround	○	○	○	○	○
Taxy	○	○	○	○	○
Take off	○	○	○	○	○
Cruise	○	○	○	○	○
Approach	○	○	○	○	○
Landing	○	○	○	○	○
When tired	○	○	○	○	○
When flying towards direct sun	○	○	○	○	○
When it feels too bright	○	○	○	○	○
Other	○	○	○	○	○

Other (please specify)

7. Eye protection and professional pilots

***When would you use your 2nd pair of sunglasses?**

	Never	Rarely	Sometimes	Usually	Always
Walkaround	◯	◯	◯	◯	◯
Taxy	◯	◯	◯	◯	◯
Take off	◯	◯	◯	◯	◯
Cruise	◯	◯	◯	◯	◯
Approach	◯	◯	◯	◯	◯
Landing	◯	◯	◯	◯	◯
When tired	◯	◯	◯	◯	◯
When flying towards direct sun	◯	◯	◯	◯	◯
When it feels too bright	◯	◯	◯	◯	◯
Other	◯	◯	◯	◯	◯

Other (please specify)

Please describe in what way the second pair of sunglasses differ from your main pair. For example, do they have a different colour or shade of tint? Is the frame a different style? How does it help you in the areas selected above?

8. Eye protection and professional pilots

Thinking about the main sunglasses that you use in the cockpit:

***How old are the sunglasses you use most often during flight?**

- ◯ < 1 month
- ◯ 1-6 months
- ◯ 6-12 months
- ◯ 1-2 years
- ◯ 2-4 years
- ◯ 4-8 years
- ◯ > 8 years

***What type of tint do the sunglasses you use most often during flight have?**

- ◯ Fixed (equal depth of colour from the top to bottom of lens)
- ◯ Graduated (lenses are darker at top the lens and lighter at bottom of lens)
- ◯ Photochromic (lenses darken in sunlight)
- ◯ Polarised
- ◯ Don't know

Eye protection and professional pilots

***What is the predominant colour of the tint in the sunglasses you use most often during flight?**

- ◯ Grey
- ◯ Green
- ◯ Brown
- ◯ Yellow
- ◯ Don't know
- ◯ Other

Other (please specify)

***What is the make of the sunglasses you use most often during flight?**

- ◯ Prescription sunglasses
- ◯ American Optical
- ◯ Bigatmo
- ◯ Bolle
- ◯ Caruso & Freeland
- ◯ Maui Jim
- ◯ Mile High
- ◯ Oakley
- ◯ Pitts
- ◯ Randolph
- ◯ RayBan
- ◯ Serengeti
- ◯ Silhouette
- ◯ V:One
- ◯ Non-brand
- ◯ Not known
- ◯ Other

If other, please specify

Eye protection and professional pilots

Examples of frame styles

Aviator

Oval / Round

Rectangular

Rimless

Wrap-around

***Which category best describes the frame style of the sunglasses you use most often during flight?**

- ◯ Aviator
- ◯ Oval / Round
- ◯ Rectangular
- ◯ Rimless
- ◯ Wrap-around

Eye protection and professional pilots

***When did someone (at an opticians) last check the fitting of your sunglasses?**

- Within last month
- 1 - 6 months ago
- 6 - 12 months ago
- More than 1 year ago
- Never

***How would you rate the overall comfort and performance of your sunglasses in the aviation environment?**

Very poor | Poor | Average | Good | Excellent

Please give any specific comments

***Did you review CAA guidance before purchasing sunglasses?**

- Yes
- No

***When purchasing sunglasses for flying, please select the importance that you would place on each of the following factors:**

	Not important	Slightly important	Quite important	Very important
Brand				
Colour of tint				
Protection from oblique or peripheral light				
Style of frames				
UV protection				

***When purchasing sunglasses for flying, please select the importance that you would place on each of the following factors:**

	Not important	Slightly important	Quite important	Very important
Comfort of frames				
Comfort of tint				

9. Eye protection and professional pilots

***Has the frequency of your sunglass use in flight changed within last year?**

- Yes
- No

10. Eye protection and professional pilots

Eye protection and professional pilots

If yes, how frequently did you use your sunglasses previously?

- ◯ <10%
- ◯ 10-30%
- ◯ 30-50%
- ◯ 50-70%
- ◯ 70-90%
- ◯ >90%

Please specify if there is a cause for this change

11. Eye protection and professional pilots

***Does glare from the sun cause you visual discomfort?**

◯ Never ◯ Rarely ◯ Sometimes ◯ Generally ◯ Always

Any specific comments?

***Does glare from the sun prevent you from visualising aircraft instruments?**

◯ Never ◯ Rarely ◯ Sometimes ◯ Generally ◯ Always

Any specific comments?

***Do you use other means of protecting your eyes from sunlight (please specify the percentage of daytime flight that you are likely to use the following). Note that if you never adopt this strategy, please select 0%.**

	0%	<5%	5-10%	10-30%	30-50%	50-70%	70-90%	>90%
I use the aircraft sun visors	☐	☐	☐	☐	☐	☐	☐	☐
I use a baseball cap	☐	☐	☐	☐	☐	☐	☐	☐
I put my hand up to prevent direct sunlight in my eyes	☐	☐	☐	☐	☐	☐	☐	☐
I adjust my seat position to prevent direct sunlight in my eyes	☐	☐	☐	☐	☐	☐	☐	☐
I use newspapers or charts against the aircraft windshield or attached to visor	☐	☐	☐	☐	☐	☐	☐	☐
I use plastic sheets/tray liners against the aircraft windshield	☐	☐	☐	☐	☐	☐	☐	☐
I have another strategy that I use	☐	☐	☐	☐	☐	☐	☐	☐

please specify other strategy, if used

12. Eye protection and professional pilots

Eye protection and professional pilots

This final section includes some questions regarding your eye health. Be assured that all the information you provide is anonymous.

***Have you been told that you are developing or have got cataract(s)?**

- ◯ Yes
- ◯ No

***Have you been told that you are developing or have got macular degeneration?**

- ◯ Yes
- ◯ No

***Have you had cataract surgery and intra-ocular lens implant(s)?**

- ◯ Yes
- ◯ No

***Are you aware of the role of diet in maintenance of eye health?**

- ◯ Yes
- ◯ No
- ◯ Don't know

***Do you regularly take vitamins or supplements?**

- ◯ No
- ◯ Yes, for general health reasons, not because I am concerned about eye health
- ◯ Yes, for both general health reasons and also because I am concerned about eye health
- ◯ Yes, specifically and solely because I am concerned about eye health

What is your age?

[ ]

***Which of the following best decribes your number of hours logged over the last 12 months?**

- ☐ less than 100 hours
- ☐ 100 - 300 hours
- ☐ 300 - 500 hours
- ☐ 500 - 700 hours
- ☐ more than 700 hours

Do you have any other comments with regard to sunlight and eye protection in flight?

[ ]

Eye protection and professional pilots

Thank you for your time today and for participating in this survey.

Appendix M: Spectrometer reliability

1) Calibration

PHE conducted a series of tests to ensure accurate calibration of the HR4000 spectrometer. Sensitivity checks were carried out at the PHE labs in Chilton, Oxfordshire in September 2011, February 2012, June 2012 and May 2013 using a 1kW Tungsten Halogen standard calibration lamp (BN 9101-548). This lamp has a known output against which the HR4000 can be assessed and is calibrated for spectral irradiance to the Physikalisch-Technische Bundensanstalt (PTB) traceable reference standards. The performance of the calibration lamp is ensured as its output can be compared against 2 stationary double grating monochromators Jobin Yvon D^3 180 (Jobin Yvon, Longjumeau, France) at the PHE laboratories. To assess the HR4000 accuracy in the UV range, measurements were taken using a longer integration time (t=2sec) to improve signal to noise ratio and optimise UV part of the spectrum.

In order to reduce the potential for stray light during in flight measurements, the HR4000 sensitivity was additionally calibrated in June 2013 to the solar spectral irradiance at solar noon on a clear day, using a scanning double-grating monochromator D^3 180 as a reference instrument. This calibration provided a good correlation (<1% error) between the HR4000 and both illuminance UV recorders used for in flight measurements.

The HR4000 spectral irradiance calibration measurements produce a calibration factor. This is the ratio of the irradiance of the certified calibration source and the measured intensity and which can then be applied either prospectively or retrospectively if required, to the flight data.

On each calibration assessment, wavelength position verification was carried out at the PHE labs using a low pressure Hg penray lamp with known mercury position lines (253.65nm, 296.73nm, 404.66nm, 435.83nm and 546.07nm). The wavelength position was also checked in CAA offices before and after each deployment. This was carried out by taking a spectral reading using the mercury peaks on a standard room fluorescent tube light (365.02nm, 404.66nm, 435.83nm and 546.07nm). On every occasion, wavelength peaks measured were within the accuracy resolution of the spectrometer and were within 0.37nm.

All calibration checks were carried out using the same CC-3-UV cosine corrected diffuser, fibre optic cable and shutter as used for all data collection. A separate calibration assessment was carried out using the 3m fibre optic cable; however, there was no measurable difference found between the cables.

2) Accurate range

Results of the performance of the HR4000 against the certified calibration lamp showed that there were increasing degrees of uncertainty of spectral measurements below 350nm. This was however, dependent on the strength of short wavelength signal of the calibration lamp and additionally, the board temperature of the HR4000. Below 350nm, greater accuracy would be obtained using multi-region measurement to improve signal to noise ratio. The instrument was assessed up to 800nm and remained sensitive in this range. The variation in sensitivity with wavelength is shown in Figure 1.

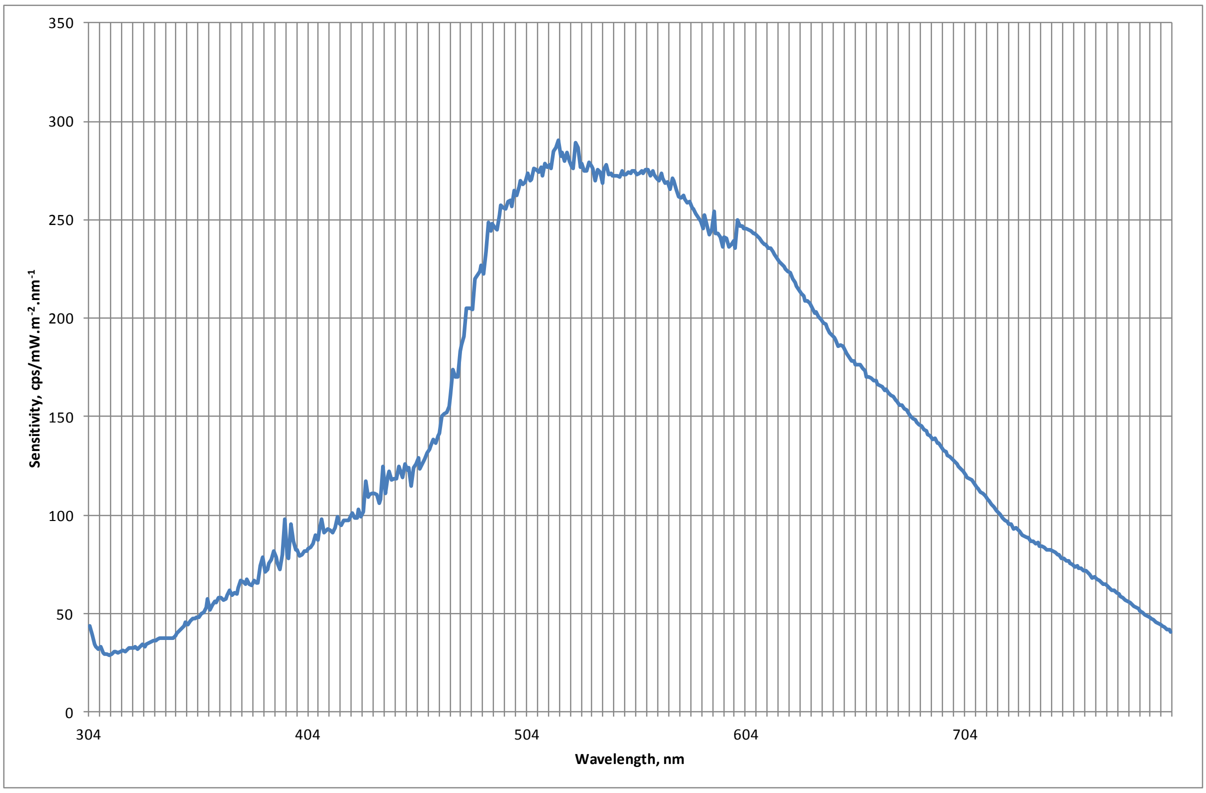


Figure 1 Summary of the variation of sensitivity of the HR4000 which peaked around 520nm.

The accuracy of the HR4000 at measuring low signals was assessed by taking measurements against the certified calibration lamp using increasingly shorter integration times. The HR4000 showed a linear response provided the signal was at least 2 standard deviations higher than the background noise level.

The angular response of the CC-3-UV was measured by varying the angle from -80° to +80° in 5 intervals of a collimated 100W tungsten halogen source to the detector and measuring the irradiance response at 400nm, 500nm, 600nm and 700nm (Figure 2).

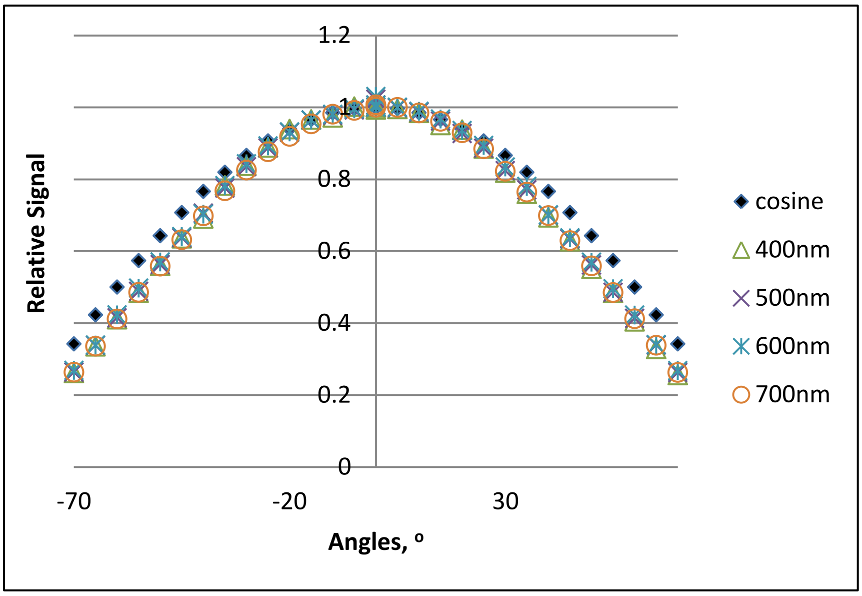


Figure 2 Angular response of CC-3-UV at various wavelengths and compared to a cosine response curve.

This was then compared to an ideal cosine response and showed that the diffuser matches the ideal cosine response within 5% for incident angles +30° to -30° and is consistent with wavelength. Between 30° to 50°, the CC-3-UV was found to underestimate between 5-10% (Figure 3).

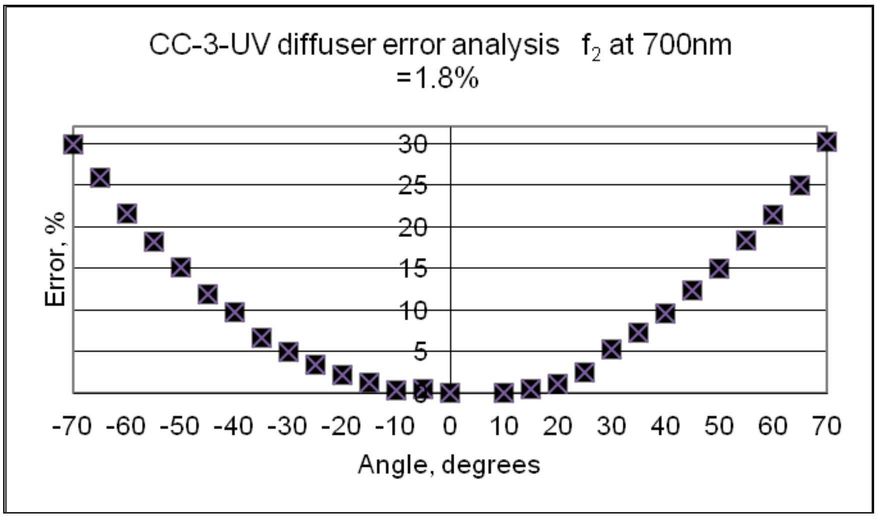


Figure 3 Percentage error of CC-3-UV diffuser from ideal cosine response

3) Variation with temperature

The performance of CCD array spectrometers are affected by variations in ambient temperature (Price et al, 2014). To ensure data reliability, a spectrometer can be operated in a temperature-controlled environment. However this was not possible on the flight deck due to power and space constraints.

For each spectral measurement, internal temperature information of the HR4000 is captured. This is known as the board temperature. To evaluate the effect of temperature, the wavelength position, sensitivity and structure of background signal were measured at the range of foreseeable operation temperatures from 10°C to 40°C.

Elevated ambient temperature caused blue-shift of wavelength position exceeding 0.5 nm at 40°C. The sensitivity change with temperature between 22°C and 35°C was within 2-3%, with respect to the sensitivity at 22°C. However, the mean of dark signal and the standard deviation of the dark signal both increased significantly with increasing integration time above 100 ms and increasing ambient temperature. This sharp increase of dark signal and, as a result, loss of signal-to-noise ratio at elevated temperatures for this instrument was considered a potential limiting factor of its use outside temperature controlled environment. To counter this issue, a dark measurement was taken immediately after every in flight spectral measurement.

When the HR4000 was temperature stabilised, the board temperature directly correlated to ambient temperature (Figure 4); thermal equilibrium of instrument lagged behind the change of ambient temperature for up to 30 min as illustrated in Figure 5. The board temperature was a better and more dynamic predictor of the HR4000 characteristics than ambient temperature when the instrument was used outside of a temperature-controlled environment.

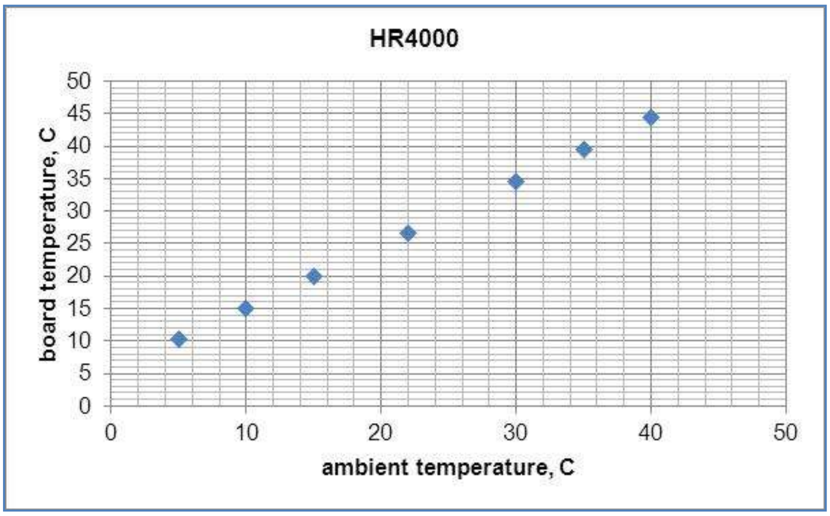


Figure 4 Correlation between ambient and board temperatures of the HR4000 in thermal equilibrium

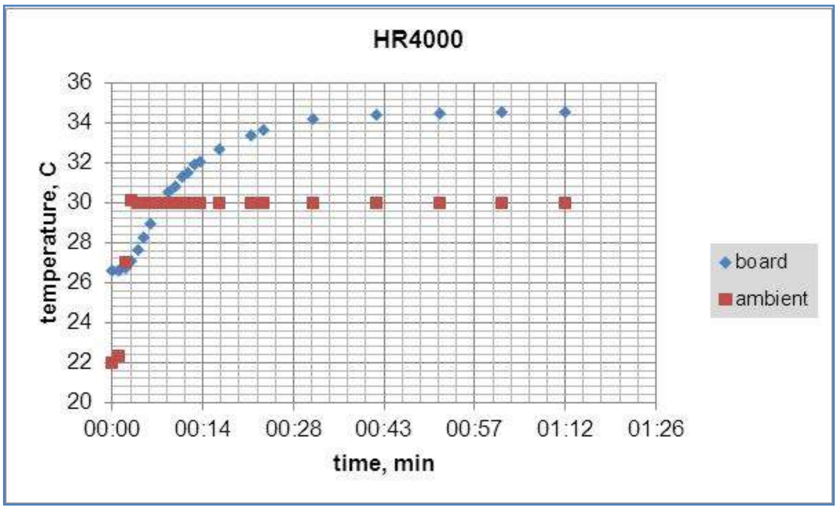


Figure 5 Time taken for HR4000 to reach thermal equilibrium

Reference

Price, L.L., Hooke, R.J. and Khazova, M. (2014) Effects of ambient temperature on the performance of CCD array spectroradiometers and practical implications for field measurements. *J.Radiol.Prot.*, 34, (3) 655-673.

Appendix N: Spectral stitching

To determine whether stitching of the spectral data in the UV and visible regions was required, the files of all three regions were examined. A two-step procedure was followed, firstly examining the UV region overlap and secondly visible. The following steps were undertaken:

UV

1. The difference between the integration times of region 2 (380-500nm) and region 3 (280-400nm) were assessed for the overlapped region of 380 – 400nm. If a large difference was observed stitching may be required, dependent on conditions 2 and 3.
2. For the file containing the region of 280 – 400nm, the value at 430nm was assessed. If it was greater than 15,500 counts after subtracting the dark signal from the raw signal, stitching could not be performed higher than 380nm due to potential signal saturation and pixel leakage. In this scenario, region 1 data were used. However, the spectral regions captured were set so this event was avoided in the majority of cases.
3. For the two files, the counts per second (cps) values, calculated by subtracting the dark value from the raw value and dividing by integration time, were compared for each wavelength. Stitching was considered from the wavelength where a difference in cps was greater than 10%.

In the case of point 2, it was expected that if saturation did occur at 430 nm, stitching could not take place above 380nm so comparison of the cps of regions 2 and 3 were only possible at the single value of 380nm. Comparing region 1 with region 3 would yield the same result as comparing region 2 with region 3 even though region 1 has a complete overlap of region 2. The reason is that the peak response from the solar visible spectrum would occur within both regions 1 and 2. Therefore, both regions should have a similar integration time and region 1 cps value should almost be identical in the majority of cases to region 2. Therefore, for the purposes of stitching, the outcome of comparison of region 1 to region 3 would be the same as for the comparison of region 2 and region 3.

For stitching, regions 1, 2 and 3 were only considered in cases of poor signal to noise ratio within the UV range of region 1. For the majority of the results, stitching was not required as the signal to noise ratio within the UV range of region 1 was of an acceptable level for examination.

A similar procedure was followed for the visible spectral overlapped regions of 1 and 2. To assess if stitching were required, the following procedure was followed:

Visible

1. The difference between the integration times of region 1 (280-1100nm) and region 2 (380-500nm) were assessed for the overlapped region. If a large difference was observed stitching may be required, dependent on conditions 2 and 3.

2. For the file containing the region of 380 – 500nm, the value at 530nm was assessed. If it was greater than 15,500 counts after subtracting the dark signal from the raw signal, stitching could not be performed higher than 440-450nm due to potential signal saturation and pixel leakage. In this scenario, region 1 data were used. However, the spectral regions captured were set so that this was avoided in the majority of cases.

3. For the two files, the counts per second (cps) values, calculated by subtracting the dark value from the raw value and dividing by integration time, were compared for each wavelength. Stitching was considered from the wavelength where a difference in cps was greater than 10%.

Where the difference in cps between the regions 1 and 2 was greater than 10% and stitching were limited to below a determined wavelength due to potential pixel leakage, stitching was possible from the start of the overlapped region (380nm) to the 'safe' wavelength point rather than to 500nm. The upper limit of stitching was therefore dependent on whether saturation takes place for the 380 – 500nm file at 530nm.

A multiple file checking software was available which extracted the above information from each set of files. The output of the program would then indicate whether stitching of the files was required.

For a set of files requiring stitching, the Spectral Stitching Program (SSP) was used (Figure 1). Once the appropriate files are selected, the wavelength range of the regions overlap were determined by SSP. SSP allows up to three spectral measurements from different regions to be interlaced together at a wavelength for each overlapping region defined by the user.

SSP plots the spectral irradiance (mW/m^2nm^{-1}) of the two sets of overlapping regions of interest in separate tabs for assessment by the user. Due to potential signal saturation and pixel leakage, the upper stitching limit determined by the file checker program was observed. Figure 2 shows an example of stitching of regions

1 and 2. In this example, stitching was not required due to good overlap of the two regions.

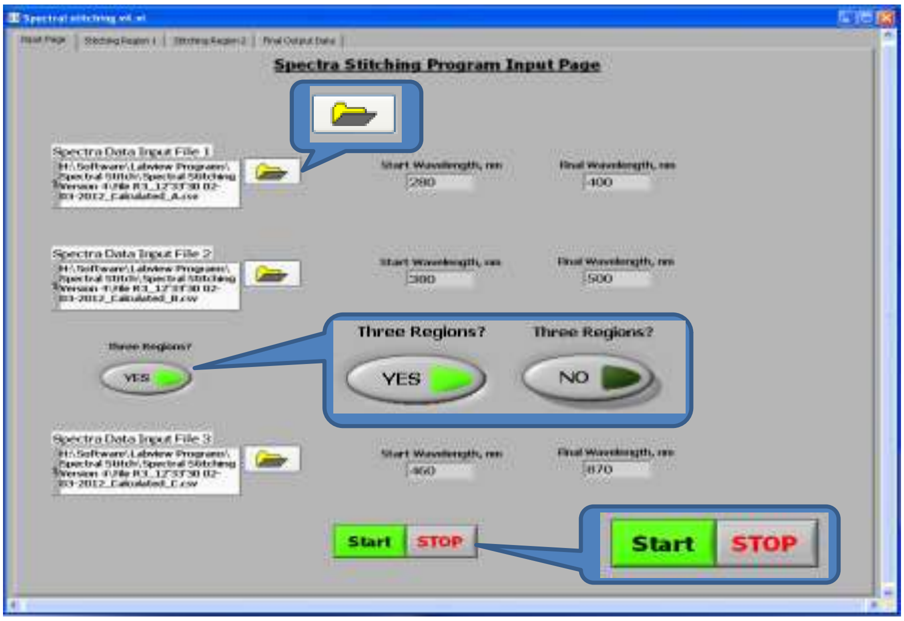


Figure 1 Screenshot from spectral stitching software showing the input of time matched region files for stitching.

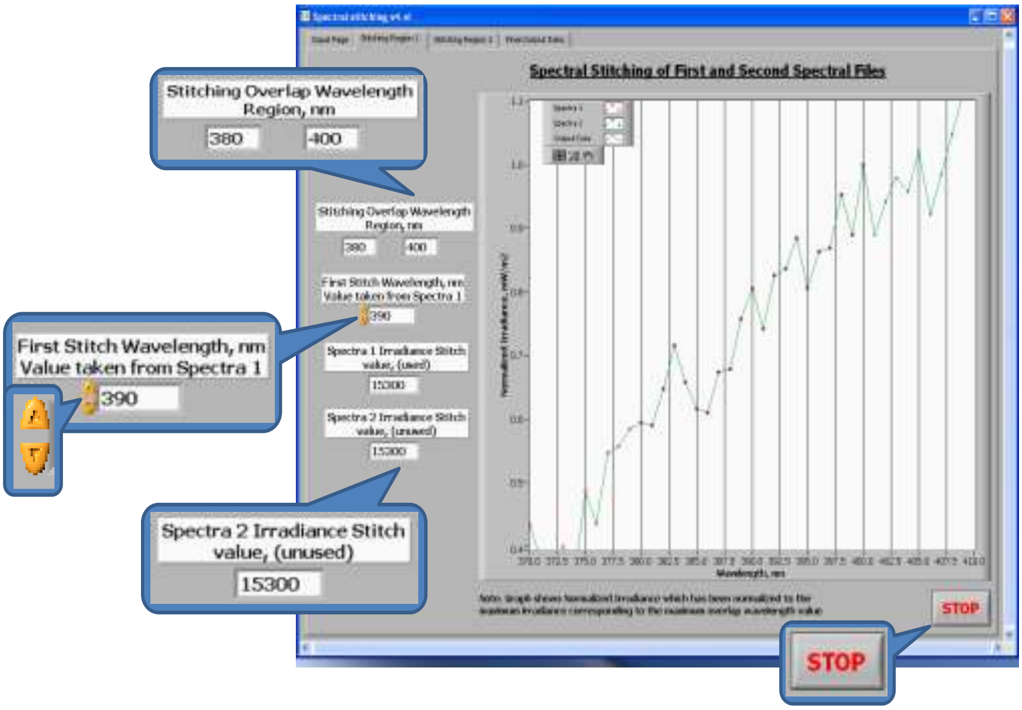


Figure 2 Output of spectral stitching software showing the frequency range overlap. The two regions in this example show good correlation and would not require stitching.

The spectral irradiance of the stitched spectra (Figure 3) was then saved as a single file in either .txt or .csv formats. In addition to the spectral irradiance (mW/m^2nm^{-1}), details of the date, spectrometer type, wavelength range and integration times of each spectral measurement were recorded.

Figure 3 Output of three regions saveable as one file in either .txt or .csv format

Appendix O: Manual illuminance data recording sheet

Date		Flight		Page
Time	Ahead	Down	Max	Comments

Appendix P: Information and request sheet for pilot sunglasses

Sunglass measurement test

We are looking to measure the transmission properties of sunglasses used by pilots.
This is being undertaken as part of a large research project investigating light exposure to the eye during flight.

We would be very grateful if you would allow us to take a couple of measurements from your sunglasses. It will only take a minute!

Thank you