CHAPTER 41
LASER EMITTERS AND FLIGHT SAFETY

1.0 PURPOSE

1.1 The purpose of this Guidance Material is to provide general information, directive and advice on measures to protect pilots of civil aircraft from accidental laser beam strikes, on or in the vicinity of an aerodrome. This guidance should be used in the planning and control of advertising, entertainment, and similar visual displays using visible laser light. The information and guidance material provided in this Chapter is primarily for the use of Aviation Safety Inspectors and Operators.

1.2 REGULATORY DIRECTIVE

a) No person shall intentionally project, or cause to be projected, a laser beam or other-directed high intensity light at an aircraft in such a manner as to create a hazard to aviation safety, damage to the aircraft or injury to its crew or passengers.

b) Any person using or planning to use lasers or other-directed high-intensity lights outdoors in such a manner that the laser beam or other light beam may enter navigable airspace with sufficient power to cause an aviation hazard shall provide written notification to the Authority.

c) No pilot-in-command shall deliberately operate an aircraft into a laser beam or other-directed high intensity light beam unless flight safety is protected. This may require mutual agreement by the operator of the laser emitter or light source, the pilot-in-command and the Authority.

d) All Aircraft (AAC) and AOC holders should ensure that their relevant Procedures / Operations Manual contains guidance information as mentioned in Section 7 of this Guidance Material, for crews on the immediate actions to be taken to mitigate the effects if their aircraft is targeted by a laser illumination.

2.0 REFERENCES

1. ICAO Doc. 9815
2. Regulation 8.8.2.9(c) of the Nigerian Civil Aviation Regulations;
3. Regulation 1.3.3 Table II (IV)(6): Special Emphasis Enforcement; Nigerian Civil Aviation Regulations
4. Checklist: OPS – 20C

3.0 INTRODUCTION

3.1 Lasers used in the vicinity of aerodromes add to the known aviation-related problems associated with high intensity lights and can have a physiological impact upon pilots which could threaten aircraft safety, particularly at critical stages of flight such as final approach. Such physiological effects can include: glare, temporary flash blindness, after-image, and, possibly, eye injury. In addition, there is the potential for laser activity to dazzle and distract pilots of aircraft, and any planned laser activity must be organised to avoid this eventuality.

3.2 Adequate lighting is necessary for all visual tasks. An excess of light, however, can detrimentally affect vision to the extent of rendering it ineffective. In aviation, a pilot may experience high levels of lighting when flying into the sun or looking at very bright artificial light sources such as searchlights. The invention (in 1957) of the laser* is a significant addition to the known aviation-related problems associated with high-intensity lights.

3.3 **Laser** is an acronym for **light amplification by stimulated emission of radiation**; this technique can produce a beam of light of such intensity that permanently damages the human tissue. In particular, the retina of the eye can be instantaneously affected even at distances of over 10 km. At lower intensities, laser beams can seriously affect visual performance without causing physical damage to the eyes. There are, however, many useful applications of laser technology, such as high-speed automatic scanning of bar codes, laser printing, welding and cutting, micro-surgery, communication by means of fibre optics, recording of music, gyroscopes, light displays and the ubiquitous laser pointer used by lecturers worldwide. Lasers are associated with almost every aspect of modern life.

3.4 Whilst protection of the pilot against deliberate or accidental laser beam strikes has been of interest to military aviation medicine specialists for many years, it was only with the advent of the laser light display for entertainment or commercial purposes and subsequent accidental illumination of civil aircraft from such displays that civil aviation medicine specialists have become more concerned.

3.5 By 2001, many pilots had experienced incapacitation following accidental laser beam strikes. Over 600 incidents have been recorded worldwide, it may be expected that most civil aircraft laser beam strikes will be inadvertent, but powerful laser emitters that can be accurately targeted are now available at relatively low cost, so the possibility of malicious use of such devices in the future cannot be ignored.

4.0 PHYSICS OF LASERS

4.1 **A basic insight into how a laser works helps in** understanding the hazards incurred when a laser emitter is used. As shown in Figure 1-1, electromagnetic radiation is emitted whenever a charged particle (e.g. an electron) gives up energy. This happens every time an electron drops from **a higher energy state**, Q_1, **to a lower energy state**, Q_0, in an atom or ion as occurs in a fluorescent light. This can also happen from changes in the vibrational or rotational state of molecules.

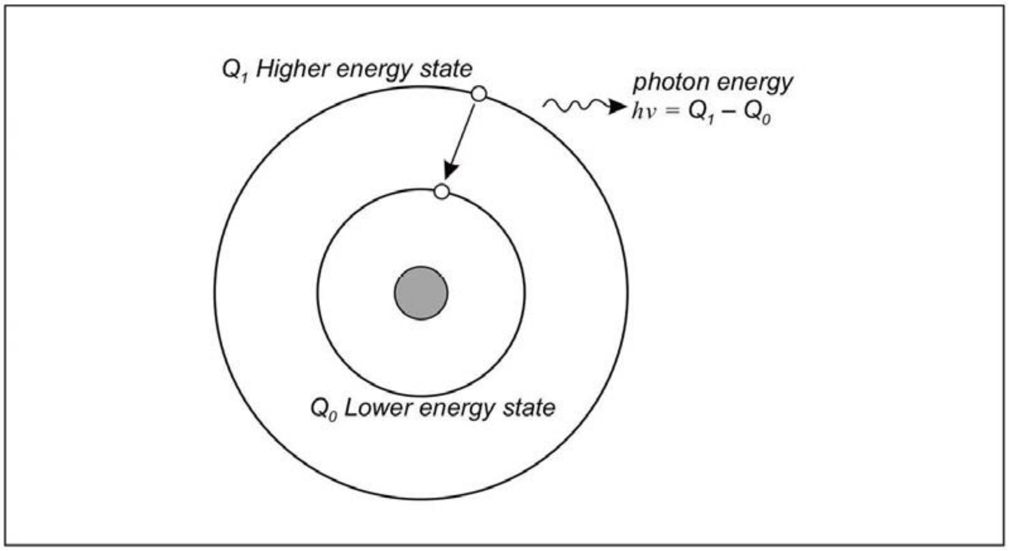


Figure 1-1. Emission of radiation from an atom by transitionof an electron from a higher energy state to a lower energy state

4.2 **The colour of light is** determined by its frequency or wavelength. The shorter wavelengths are the ultraviolet (UV) and the longer wavelengths are the infrared (IR). The smallest particle of light energy is described in quantum mechanics as a photon. The energy in joules, *E*, of a photon is determined by its frequency, *v* in hertz (Hz), and Planck’s constant, *h* (6.63×10^{-34} J □ s), as follows.

$$E = h \times v$$

4.3 The velocity of light in a vacuum, *c*, is 3×10^8 metres per second (m/s). The wavelength, λ, of light is related to the frequency as follows:

$$\lambda = \frac{c}{v}$$

4.4 The difference in energy levels across which an excited electron drops determines the wavelength of the emitted light. As the energy increases, the wavelength decreases.

5.0 LASER HAZARD EVALUATION

5.1 PURPOSE

The purpose of a laser hazard evaluation is to minimize the potential for injury to personnel from a laser emitter. As part of this evaluation, the Accessible Emission Limit (AEL), Laser Classification, Nominal Ocular Hazard Distance (NOHD) and Optical Density (OD) required for personnel protection are determined. In addition, engineering and administrative control measures should be considered.

5.2 BACKGROUND

The retina is especially sensitive to laser light beams for two reasons:

a) irradiance from a conventional source, such as a light bulb, is reduced with increasing distance from the source according to the inverse square law, i.e. the irradiance is reduced as a function of the square of the distance from the source. Since a laser beam is collimated, it does not follow the inverse square law and its irradiance for a given power output is usually far greater at a given distance than that from a conventional light source; and

b) if light from a conventional source is focused by means of a reflecting surface, as in a searchlight, the irradiance downrange of the source is greater than would be expected according to the inverse square law. However, it is not possible to collimate conventional light energy. For a given power output, a conventional light source cannot, therefore, produce a light beam which has an irradiance similar to that of a laser beam.

5.2.1 Collimated light rays reaching the eye are focused by the cornea and lens onto a very small area of the retina similar to the way parallel light rays from the sun can be focused by a magnifying glass into a spot of sufficient irradiance to burn paper. A laser beam can have an irradiance which exceeds that of the sun, even if the laser is of relatively low power (e.g. 5 milliwatt) and the observer is at a considerable distance from the source. In this context, the focusing ability of the eye is very important. Laser light passing through a pupil of 7 mm diameter can be focused into a spot on the retina only 2–20 µm big. It can be calculated that the irradiance of collimated light is increased up to 100 000 times from the cornea to the retina.

5.3 LASER HAZARD CLASSIFICATION

Laser hazard classifications are used to indicate the level of laser radiation hazard inherent in a laser system and the extent of safety controls required. These range from class 1 lasers, which are safe for direct beam viewing under most conditions, to class 4 lasers, which require the strictest controls.

5.3.1 Classification is based only on unaided and 5-cm-aided viewing conditions. This means that the power or energy that can pass through the limiting aperture (known as the effective power or energy) is compared to the appropriate AEL when determining hazard classification. The laser classification system is summarized below:

Class 1 lasers
Class 1 lasers are lasers which cannot emit radiation in excess of the class 1 AEL.

Class 2 lasers
Class 2 lasers are low-power visible (400 to 700-nm wavelength) lasers and laser systems that can emit an accessible output exceeding the class 1 limits but not exceeding the class 1 AEL for a 0.25 second exposure duration.

Class 3 lasers
Class 3 is subdivided into 3a and 3b (3A and 3B in international standards). Class 3a lasers are medium power lasers with an output between 1 and 5 times the class 1 AEL (class 2 AEL for visible lasers) based on the appropriate exposure duration. All other lasers at any wavelength not classified as class 1 or class 2 with a power less than 500 mW and unable to produce more than 125 mJ in 0.25 seconds are defined as class 3b (3B).

Class 4 lasers
Class 4 lasers are high-power lasers including all lasers in excess of class 3 limitations. These lasers can often be fire hazards. Both specular and diffuse reflections are likely to be hazardous.

5.4 OTHER FACTORS

In performing a laser hazard evaluation, other issues must be considered. Things such as critical task impairment, properly working safety interlocks, standard operating procedures, and signs and labels are integral factors in establishing a safe environment for laser operation. The significance of specific control measures depends upon the laser hazard classification. A start-up delay, for example, should not be necessary for a class 2 laser device. Applicable national or international laser safety standards list the control measures required for each laser hazard class.

5.4.1 Non-Beam hazards

Although laser radiation is the most obvious hazard associated with laser systems, many other hazards should be considered in a laser hazard evaluation. These are known as non-beam hazards. The following list shows several non-beam hazards common to laser use:

- collateral radiation
- compressed gases
- confining space
- cryogenics
- electrical
- electromagnetic interference
- ergonomics
- explosion
- fire
- laser dyes
- mechanical
- noise
- toxic materials
- trailing cables/pipes
- waste disposal
- X-rays

6.0 LASER BEAM BIOEFFECTS AND THEIR HAZARDS TO FLIGHT OPERATIONS

6.1 INTRODUCTION

The development of the laser and the industrial application of laser technology stand out as some of the most significant scientific contributions of the 20th century. Presently, lasers are found virtually everywhere, from supermarkets and schools to satellites and operating rooms, and have become fundamental components in consumer products and complex industrial devices, including sophisticated weapon systems. The accessibility of the technology and the significant reduction in cost place lasers at almost everyone’s disposal. Furthermore, the application of laser technology to modern society is still emerging and its future potential appears boundless.

6.1.1 However, if used improperly, laser energy also poses a significant biohazard. Consequently, even the most innocuous laser pointer can become a safety hazard, either through direct bioeffects or by causing a disruption of critical performance tasks in hazardous situations.

6.1.2 Not surprisingly, as lasers proliferate, an ever-increasing number of laser beam-related incidents, some from misadventure and others caused by intentional misuse, have been reported. A significant number of these incidents involve aircraft operations, both civil and military. Low flying helicopters, as used by police and for medical evacuation, are particularly vulnerable, not only because of their proximity to the ground but also because of their proximity to ground-based lasers. In some aviation environments, even the most trivial of laser beams have the potential to become a lethal threat, e.g. by distraction of aircrew during a critical phase of flight. This section will elaborate on the bioeffects and damage mechanisms of laser beam energy particularly from the perspective of its effects on aircraft operations. However, the ongoing development of new lasers and the continued advances in research associated with lasers and their effects make this a vast and still evolving area of biological science.

6.1.3 Depending on power and other physical characteristics, laser beams have the potential to generate a variety of bioeffects, including the capacity to vapourize biological tissue, either in part or in full, sometimes destroying the entire organism. This section, however, will be limited to those laser beam bioeffects likely to be encountered within civilian aircraft operations and primarily those affecting the skin and the eye. The major part of this section will address this risk from the perspective of its potential effect on vision, since this is the primary aeromedical concern.

6.2 THE HAZARD

The spectrum of electromagnetic radiation ranges from the shortest of cosmic rays at 10–5 nm to very long waves in the order of 1014 nm (100 km), as associated with communications and power sources. Each of these wavelengths is associated with photons of varying energy. The shorter the wavelength, the higher the energy associated with the photons at that specific wavelength. For tissue interactions at the atomic level, the higher the level of energy associated with these photons, the higher the risk for biological effects. Therefore, radiation of shorter wavelengths has the greatest potential to be biologically hazardous.

6.2.1 The sun is the source for most of the natural electromagnetic radiation reaching the earth. Fortunately, the atmosphere protects the surface of the planet from many of these wavelengths and their associated hazards, but a significant portion of the electromagnetic spectrum still penetrates this protective barrier to become an environmental biohazard. In addition, industrial sources can create hazardous radiation in any environment.

6.2.2 The optical radiation portion of the electromagnetic spectrum can interact with the human eye and skin. Optical radiation extends from the shortest ultraviolet wavelength, at 100 nm, through the visible spectrum up to and including longer IR wavelengths around 1 mm (106 nm), such as those associated with radar. The optical radiation portion of the electromagnetic spectrum can be a biohazard when associated with visible and invisible laser beams.

6.2.3 The atmospheric contents normally shield the surface of the planet from UVC radiation. Without this protection, biological life on the planet would not be possible. Although not a naturally occurring biological threat, any of these wavelengths can be artificially generated and exploited by means of laser-based technology.

6.2.4 It is the acute disruption in visual performance and the potential of laser beams to induce ocular damage that are of paramount importance to aircrew in the performance of their duties and which implies a threat to flight safety.

6.3 OCULAR LASER BEAM

6.3.1 Damage Terminology

There are a few specific terms relevant when addressing laser-beam damage in an eye. These are:

a) ***Maximum permissible exposure (MPE).*** The MPE is that level of laser beam energy below which exposure to a laser beam is not expected to produce adverse biological damage. There are differences in MPE calculations depending on whether the laser beam is pulsed or continuous. MPEs for the skin and eye for any laser beam and exposure condition are available in the American National Standards Institute ANSI Z136-1-2000,2 the International Electrotechnical Commission (IEC) 60825-1: 19983 and other related international documents.

b) ***Nominal ocular hazard distance (NOHD).*** The NOHD is the distance from a laser beam beyond which the MPE is not exceeded. Within the NOHD, the MPE may be exceeded and biological damage may be expected. It therefore defines the so-called “safe range” from any given laser emission. That “safe range” relates to actual biological damage and not necessarily to disruptions in visual performance.

c) ***Minimal ophthalmoscopically visible lesion (MOVL).*** The MOVL can be defined as the minimal lesion caused by a laser beam exposure, which can be seen by direct ophthalmoscopy. Tissue damage may not be immediately apparent and it may take over 24 hours for a lesion to become visible. In general, the energy required to produce an MOVL increases as a function of distance from the fovea on the retina. Radiant exposure and irradiance thresholds capable of creating MOVLs have been determined for most common laser beam wavelengths.

6.4 LASER BEAM BIOEFFECTS AND AIR OPERATIONS

This section will elaborate on the individual features of the bioeffects continuum as they relate to the eye and air operations. These bioeffects include:

- Distraction
- Glare (also referred to as dazzle)
- Flash-blindness
- After-images
- Scotomas
- Retinal burns
- Retinal haemorrhages
- Globe rupture
- Other

6.4.1 Distraction

When a person sees a bright light, particularly at night, the natural reaction is to look at it. While in flight, aircrews are particularly sensitive to unexpected bright lights. Such a light may be perceived as representing a potential threat, such as the prospect of a collision with another aircraft or a ground obstacle. Pilots, because of their extensive training in combination with normal biological reflexes, instinctively divert their attention toward any new unexpected light in order to assess its significance. A distraction that occurs during a critical phase of flight could have serious consequences unrelated to the light source's ability to induce actual ocular damage. If the light is a laser beam illumination that exceeds the MPE, then even a brief direct visualization of the laser beam before a compensatory blink occurs could result in irreversible biological damage, as well as acute disturbances in visual performance.

6.4.1.1 Due to the strobe effect of some pulsed laser beams, they can be more distracting than CW damage has occurred. Therefore, there may be a period of time during which the exposed aircrew members may be functionally disabled, visually and/or psychologically. Reactions to such events are an unpredictable aspect of human nature, but experience has taught us that significant exposures to laser beams under these conditions can result in serious psychological disruptions, inciting panic and necessitating transfer of control of the aircraft to the other flight crew members.

6.4.2 **Glare and Dazzle**

Glare and dazzle are two terms often used interchangeably that refer to temporary disruptions in visual acquisition without biological damage. Glare can be caused by virtually any light and is particularly disruptive under scotopic viewing conditions, especially when the eyes are fully dark-adapted. However, any glare source in the cockpit is undesirable. Glare is regarded to be a source fixed effect, meaning that as the position of gaze shifts away from the light source, glare effects are diminished.

6.4.2.1 Discomfort glare refers to glare of high enough illumination that forces the viewer to turn away. Discomfort glare tends to be exacerbated when the overall ambient illumination is low. Disability glare refers to the inability to see an object because of the light. Veiling glare represents the ability of glare to impede visualization of structures around the glare source beyond the actual size of the glare source itself and is a more functional representation of the true level of visual performance degradation.

6.4.3 Flash-blindness

Flash-blindness is a visual interference effect caused by a bright light that persists after the light is terminated. Flash-blindness persists while an eye attempts to recover from an exposure to the bright light. The ability of any given light source to induce flash-blindness is directly related to the brightness of the light and the level of dark adaptation in the target eye at the time of the exposure.

6.4.4 After-images

After-images refer to perceptions, or so-called after-effects, which persist following illumination with a bright light. They are often described as light, dark or coloured spots following exposure. Such after-images are essentially a type of flash-blindness, although after-image effects may last for more prolonged periods of time; often well beyond recovery of the ability to perform visual tasks required while in the cockpit.

After-images can occur following illumination with both visible and invisible radiation. The latter reflects normal retinal sensitivity to some of these wavelengths, i.e. to some limited UV or IR bands, or is an expression of actual biological damage.

6.4.5 Scotomas

A scotoma is an after-effect which is either temporary (reversible) or permanent. A scotoma in its most benign form represents a resolving residual after-image. However, it can also be permanent and may thus reflect the earliest sign of permanent biological tissue damage. Scotomas typically follow flash-blindness reflecting normal biochemical recovery of photosensitive pigments in both rods and cones. The typical scotoma can be caused by exposure to a bright light but can also be caused by some non-visible wavelengths.

6.4.6 Retinal Burns

A retinal burn represents more significant and permanent damage induced by intense radiation and is very characteristic of laser beam induced phototoxic damage. A laser beam focused on the retina is more likely to cause injury than a non-focused beam. The ability of a laser beam to induce such damage is used as a surgical tool to treat certain ophthalmological disorders, such as retinal tears and diabetic retinopathy.

6.4.6.1 It is the ability of a laser beam to induce a retinal burn that is one of the most ominous unwanted effects in a normal eye, and any resultant visual consequences will be a direct function of the size and location of the lesion.

6.4.7 Retinal Haemorrhages

A retinal haemorrhage will occur if a laser beam disrupts a blood vessel somewhere in the eye. The characteristics of that haemorrhage will depend on the location of the damaged blood vessel within the retina, its distribution and the orientation of the cell structure at the disruption site. Haemorrhages involving superficial retinal vessels will tend to follow the nerve fibre layer and assume a flame-shaped configuration as the blood follows the nerve fibres out radially from the optic nerve.

6.4.7.1 A haemorrhagic event can have significant visual impact. Recovery will depend on the location of the bleed and other induced cytoarchitectural disruptions, as well as the rate of reabsorption of the blood, e.g. from the vitreous body, where it acts as a light-blocking filter. In general, blood in the vitreous cavity will take approximately six to twelve months to resolve spontaneously but will not always do so.

6.4.8 Globe Rupture

It is possible with a laser beam to disrupt tissue to such an extent that neither a burn nor a haemorrhage occurs, but rather a tear in the tissue is caused. This can be a deleterious effect from exposure to high-peak power laser beams of certain wavelengths.

7.0 OPERATIONAL FACTORS AND TRAINING OF AIRCREW

7.1 BACKGROUND

An increasing incidence of in-flight laser beam illuminations of flight crew personnel has been reported in recent years. Incidents have occurred primarily near airports located in close proximity to large cities, resort destinations and entertainment venues. Such illuminations have resulted in aversion responses (blinking, squinting, head movement), Temporary Visual Impairment (TVI), Temporary Vision Loss (TVL), a variety of psychological effects and evasive actions. These incidents made it clear that TVI at illumination levels much lower than those normally associated with physical eye injury could affect flight safety.

7.1.1 There are two situations where outdoor laser operations may compromise aviation safety. The first is where the MPE is exceeded and physical injury to the eye can occur. The second is the situation where the MPE is not exceeded, but where there is a potential for functional impairment, such as flash-blindness, after-image and glare that can interfere with the visual tasks of the pilots during critical phases of flight. The two excerpts above are believed to be examples of the second situation.

7.1.2 There are obvious flight safety risks associated with laser beam illumination during critical phases of flight (especially procedures requiring steady-state turns). These are caused by ocular, vestibular and psychological effects, which individually or combined may lead to loss of situational awareness (LSA). TVI leaves the pilot reliant upon other sensory input, which may provide inadequate but compelling information, resulting in incorrect decisions. TVI can lead to startle, distraction, disruption, disorientation and in extreme cases, complete incapacitation.

7.1.3 Pilots receive most of their flight information visually, and in order to maintain situational awareness in a dynamic environment, they rely on frequent reference to their instruments. This reliance is greater at night and becomes total in instrument meteorological conditions (IMC).

7.1.4 It is important to understand how trained pilots interpret, integrate and process information without visual reference to the outside world. Thorough instrument flight training is a prerequisite for maintaining normal task performance, information integration and situational awareness when operating under instrument flight rules (IFR).

7.1.5 Pilots use a visual scan technique of glancing at, rather than dwelling upon, the flight instruments. Pilots construct mental images of their position in space from information provided by the flight instruments. Spatial orientation is maintained through the brain’s comparison of visual inputs with a pre-existing mental model. When conditions permit, this model is continually updated with reference to the outside world for comparison and processing.

7.2 SITUATIONAL AWARENESS

Situational awareness (SA) is the accuracy by which a person’s perception of his environment mirrors reality. SA is determined by several factors. Anything that leads to a loss of SA can create a flight safety hazard. One of the most critical factors, and the one most likely to be affected by laser beam illumination, is spatial orientation.

7.2.1 Loss of spatial orientation is called spatial disorientation (SD). It can be classified into three types:

- Type I (unrecognized SD) occurs when a person is unaware of being disorientated;
- Type II (recognized SD) occurs when a person is aware of being disorientated and is able to compensate for it; and
- Type III (incapacitating SD) occurs when a person is aware of being disorientated but is unable to compensate for it.

7.2.2 A laser beam illumination may cause all three types of SD but is most likely to cause Types II and III.

7.3 ORIENTATION IN FLIGHT

Orientation in flight is determined primarily by cues provided by the following four senses:

a) ***Sight (vision).*** This is the single most important sense for maintaining spatial orientation during flight. When vision is impaired, spatial orientation is degraded because motion and position cues provided by other senses are not reliable during flight.

b) ***Vestibular sense (sense of equilibrium).*** The vestibular apparatus provides information from the inner ear about motion and balance. In addition, the middle ear provides information about ambient pressure changes. Normally, visual input will suppress input from other senses. Because flight motion is different from that of everyday activities, the loss of visual input is critical, as vestibular information alone may result in illusory perception of flight attitude and motion. For example, to stimulate the inner ear, an angular acceleration of 0.5 to 2.2 degrees per second per second is required. When the angular acceleration ceases, such as when a constant rate turn has been established, the vestibular apparatus is no longer able to detect the turn. If visual input is absent, pilots will not recognize that the aircraft continues to turn.

c) ***Proprioception (kinaesthetic sense).*** A variety of sensory nerve endings in the skin, the capsules of joints, muscles, ligaments and deeper supporting structures are stimulated mechanically and, hence, are influenced by the forces acting on the body. These proprioceptive mechano-receptors provide useful equilibrium information based on sensation of position and movement. The kinaesthetic sense is better known to pilots as “seat-of-the-pants”. Alone, the kinaesthetic perception of an aircraft’s attitude in space is unreliable but can easily be overcome by more vital sensory input.

d) ***Hearing (audition).*** The auditory system provides information about sound level, pitch and direction. Pilots learn to recognize certain sounds during flight. For example, airflow over the windscreen during acceleration and deceleration of the aircraft and the change in pitch as the engine power-setting changes can be detected.

7.3.1 Loss of visual references caused by a laser beam illumination, coupled with inadequate information from the vestibular apparatus, the proprioceptive mechano-receptors and the auditory system, may result in SD (often referred to by pilots as “vertigo”), which can lead to accidents. Disorientation demonstration courses and laser-awareness training are therefore recommended.

7.4 PREVENTATIVE PROCEDURES

Pre-flight procedures

- Notices to Airmen (NOTAMs) should be consulted for location and operating times of laser activities and alternate routes should be considered.
- Aeronautical charts should be consulted for permanent laser activities (theme parks, research facilities, etc.).

In-flight procedures prior to entering airspace with known laser activity

- Exterior lights should be turned on to aid ground observers in locating and identifying aircraft.
- The autopilot should be engaged.
- One pilot should stay on instruments to minimize the effects of a possible illumination.
- Flight deck lights should be turned on.

In-flight procedures during and after laser beam illumination of the cockpit

7.4.1 If a pilot is exposed to a bright light suspected to be a laser beam, the following steps are recommended to reduce the risk unless the specific action would compromise flight safety:

- Look away from the light source.
- Shield eyes from the light source.
- Declare visual condition to other pilots.
- Transfer control of the aircraft to another pilot.
- Switch over to instrument flight.
- Engage autopilot.
- Turn up the cockpit lights to minimize any further illumination effects.
- Manoeuvre or position the aircraft such that the laser beam no longer illuminates the flight deck.
- As soon as flight safety allows, check for dark/disturbed areas in vision, one eye at a time. If either pilot is incapacitated to a degree that may affect the

safety of the aircraft, declare an emergency (PAN or MAYDAY as appropriate).

- Assess visual function, e.g. by reading instruments or approach charts.
- Avoid rubbing eyes.
- Notify air traffic control (ATC) of a suspected inflight laser beam illumination and, if necessary, declare an emergency.

7.4.2 It is important to notify appropriate authorities of a suspected in-flight laser beam illumination. Upon landing, the pilot should notify the authorities and provide details about the incident, then seek immediate medical evaluation, preferably by a qualified vision specialist. Documentation of incidents and medical examinations are covered in Sections 9 and 10, respectively.

8.0 AERONAUTICAL ASSESSMENT

8.1 The procedures outlined below may be used to evaluate the potential effect of laser activity on aircraft operations. The proponent should use the NOTICE OF PROPOSAL TO CONDUCT OUTDOOR LASER OPERATIONS FORM and instructions in Appendix A to notify the NCAA in sufficient time to allow an aeronautical assessment to be completed.

8.1.1 The NCAA shall:

a) determine the location of the laser activity and the laser MPE and NOHD;

b) plot the LFFZs, LCFZs and LSFZs at aerodromes;

c) establish additional LSFZs, if required, to protect locations of aviation activity that may also be affected, such as substantial helicopter traffic operating below 300 m (1 000 ft), VFR corridors, the airspace around high-energy lasers used to support astronomical observatories, active training areas, etc.;

d) consider the laser operations in relationship with the established zones. Use the MILs established by the NCAA when evaluating laser activities in proximity to an aerodrome;

e) review airspace and aircraft operations that may be affected by the proposal;

f) coordinate with local officials, e.g. aerodrome managers, air traffic managers, military representatives, local police organizations;

g) convene a local laser working group (LLWG) if the operations appear to be complex or controversial;

h) consider the proponent’s proposed mitigation measures and any additional measures taken to ensure that aircraft operators will not be exposed to laser emissions that have the potential to impair their performance of duties. Such measures include, but are not limited to, physical, procedural, manual and automated control measures;

i) compile a cumulative impact assessment on permanent or long-term laser operations effects on local operations;

j) assess the capability of the affected ATC facilities to provide real-time management of air traffic to ensure no cockpit illuminations by the laser beams;

k) coordinate with the proponent, identify objectionable effects and negotiate appropriate mitigation to protect aviation safety; and

l) communicate to the proponent and all participating authorities the completed aeronautical assessment. If the proposal is complex or controversial, the NCAA shall document all pertinent information and disseminate copies as appropriate.

8.2 CONTROL MEASURES

Physical, procedural and automated control measures established to ensure that aircraft operations will not be exposed to levels of illumination greater than the respective MILs considered acceptable should meet one or more of the descriptions listed below:

a) ATC control measures:
1) NOTAM;
2) Voice advisory (e.g. automatic terminal information system (ATIS), pilot-controller communications);
3) Airspace restrictions;

whereas the proponent must ensure that the operator control measures are in accordance with one or more of the following:

b) Operator control measures:
  1) The laser beam may be physically blocked (terminated beam) to prevent laser light from being directed into protected volumes of airspace.
  2) The laser beam divergence and output power or pulse energy emitted through the system aperture may be adjusted to meet appropriate exposure levels.
  3) Beams can be directed in a specific area. Directions should be specified by giving bearing in the azimuth scale 0–360 degrees and elevation in degrees ranging from 0–90 degrees, where 0 degrees is horizontal and 90 degrees is vertical. Both true and magnetic bearings should be given.
  4) Manual operation of a shutter or beam termination system can be used in conjunction with airspace observers. Observers should be trained and able to see sufficient airspace surrounding beam paths to terminate the beam prior to illumination of aircraft.
  5) Scanning the laser beam may reduce the level of illumination; however, it may increase the potential risk of illumination.

6) Automated systems designed to detect aircraft and automatically terminate or redirect the beam or shutter the system may be used. The proponent should include detailed information that describes the operation of the automated system, its effectiveness and how it can be tested for full functionality prior to each use.

8.3 DETERMINATIONS

If the proponent's notification satisfies the requirements of the aeronautical assessment, the NCAA shall issue, as a minimum, the following:

a) a statement advising the proponent that his notification satisfies the requirements of the NCAA and is approved subject to conditions or limitations (such as aircraft spotter requirements), as applicable;

b) a statement to the proponent that changes should not be incorporated into the proposed activity once permission has been granted, unless approved by the NCAA in writing;

c) a statement that the proponent notifies the NCAA or their designated representative of any changes to show start/stop times or cancellation 24 hours in advance;

d) a statement that approval does not relieve the sponsor or operator of responsibility for complying with the mitigation agreed upon, the laws, ordinances or regulations of any relevant authority; and

e) NOTAM. (See examples in 7.5.4¬.)

8.3.1 If the proponent's notification does not satisfy the requirements of the aeronautical assessment, the NCAA should issue a statement advising the proponent that an objection is being issued. Specifically, it should indicate why the proponent does not satisfy safety requirements, and that new data or other appropriate information may be submitted for consideration. If negotiations to resolve any objectionable effects have not been successful, the objection should stand.

8.3.2 To enhance aviation safety, a NOTAM should be prepared alerting pilots of known laser activities. It is important to emphasize the hazardous effects and other related phenomena that may be caused by laser beams.

8.4 INCIDENT-REPORTING REQUIREMENTS

Rapid notification of an incident will assist in the investigation and possible enforcement action against the offender. The Incident Report Form in Appendix B will ensure appropriate monitoring unauthorized use of lasers in airspace.

9.0 DOCUMENTATION OF INCIDENTS AFTER SUSPECTED LASER BEAM ILLUMINATION

9.1 BACKGROUND

Laser beams with the potential to compromise flight safety may be visible or invisible. Laser beams may cause damage to the retina, especially at higher levels of exposure. The bright light from visible laser beams can cause glare, afterimages and flash-blindness. Exposure to invisible laser beams may result in pain, vision loss or skin burns, but they are not normally associated with glare and flash-blindness.

9.1.1 Damage to the tissue of the eye's cornea and conjunctiva requires a higher exposure level than that required to cause damage to the retina. This is due, in part, to the eye's natural focusing mechanism that can increase the energy per unit area delivered to the retina. Besides glare, flash-blindness and after-images, other symptoms of laser beam light exposure may include pain, eye fatigue, tearing, eye irritation and headache. Laser beam light can and has interfered with safe and efficient performance of flight procedures by causing temporary distraction, disorientation and visual incapacitation.

9.2 PROCEDURES

Whenever an unexpected illumination by an unknown source occurs, a laser incident should be suspected and reported. It is recommended that all suspected laser beam incidents be reported to the national aviation medicine and flight safety authorities. In general, individuals should, without delay, consult an optometrist, ophthalmologist or designated medical examiner whenever they have experienced a suspected laser beam exposure. Those with persistent symptoms or abnormal clinical findings may require referral to an ophthalmologist for further medical evaluation and treatment.

Note.— Chapter 7, entitled "Medical Examination Following Suspected Laser Beam Illumination", provides guidance for evaluating aircrew and other aviation personnel who may have been injured or incapacitated by a laser beam illumination.

9.3 DOCUMENTATION

Documentation of a suspected laser beam illumination incident has three important functions. First, it provides information on the effectiveness of current policies and procedures used to protect the navigable airspace against hazardous laser beams. Second, it provides a protocol for medical assessment. Third, it provides updates on new devices or sources of hazardous laser beams that may affect visual performance.

9.3.1 Guidance on how to document suspected laser beam illumination incidents is provided in Appendix B. The two forms (Suspected Laser Beam Incident Report and Suspected Laser Beam Exposure Questionnaire) may be used for investigation of illumination incidents. The report should be completed by the illuminated persons as soon as possible after the incident. The questionnaire may be used by an official of the NCAA during the initial interview.

10.0 MEDICAL EXAMINATION FOLLOWING SUSPECTED LASER BEAM ILLUMINATION

10.1 GENERAL

All cases of suspected laser beam exposure should be promptly reported to the medical section of the NCAA. In cases of suspected laser beam exposure, two forms should be used:

a) Suspected Laser Beam Incident Report. This form is to be completed by the persons illuminated.

b) Suspected Laser Beam Exposure Questionnaire. This form may be used by the NCAA during the initial interview of an exposed person.

Note.— Samples of these two forms can be found in Appendix B.

10.1.2 The following information provides guidance for the medical examination and evaluation of those who may have been exposed to a laser beam.

10.2 PROCEDURE

A basic ocular examination should be performed on any person suspected of having been exposed to a laser beam to verify that no permanent damage has occurred and to confirm normal ocular health. An optometrist, ophthalmologist or a designated medical examiner may complete the basic examination.

10.2.1 Basic ocular examination

- History (review Suspected Laser Beam Exposure Questionnaire, if available)
- External examination
- Best corrected visual acuity (near and far) in each eye separately
- Amsler grid for each eye separately (see Appendix C)
- Stereopsis (specify test used)
- Colour-vision testing with pseudoisochromatic plates of each eye separately
- Confrontation visual fields of each eye separately
- Nondilated funduscopy on each eye separately

10.2.2 If the results of this examination are normal and the person does not have persistent visual complaints, further examinations are not necessary.

10.2.3 If the results of the basic examination are abnormal or questionable, an intermediate ocular examination to assess the condition of the person's eyes should be performed. An optometrist or an ophthalmologist may complete the intermediate examination.

10.2.4 Intermediate ocular examination

- Pupils of each eye separately
- Slit lamp of each eye separately
- Automated visual fields of each eye separately
- Motility (ductions and versions; cover test)
- Dilated fundoscopy on each eye separately

10.2.5 If the results of this examination are normal and the person does not have persistent visual complaints, further examinations are not necessary.

10.2.6 If the results of the intermediate ocular examination are abnormal or if visual complaints persist, the person should be referred to an ophthalmologist (preferably a retinal specialist), as advised by the aviation medicine section of the NCAA. This ophthalmologist should conduct an advanced ocular examination.

10.2.7 Advanced ocular examination

- Retinal photography
- Comprehensive testing of colour vision (to include blue/yellow tests)
- Electrodiagnostic tests, as needed
- Scanning laser ophthalmoscopy, as needed
- Fluorescein angiography, as needed

11.0 INSTRUCTIONS FOR FILLING OUT NOTICE OF PROPOSAL FORM (page 1)

11.1 The information in this form will be used by the NCAA to perform an aeronautical study to evaluate the safety of a proposed laser operation. Provide all information that the Authority may need to perform the study. If additional details are necessary, list these in the "Attachments" section of this form.

11.1.1 **To:** Enter the name, address, phone and fax of the NCAA's Office responsible for the area which includes the laser operation site. (A list of Offices is available at the end of these instructions.)

11.1.2 **From:** Enter the name, address, phone, fax, and e-mail of the applicant. This is the party primarily responsible for the laser safety of this operation. In some cases, the applicant is a manufacturer or a governmental agency, and the laser is located at a different site. In such a case, list the applicant here; the site location is filled in elsewhere in the form.

11..1.3 Report date: This is the date the report is prepared or sent to the Authority. It is not the date of the laser operation.

1. **GENERAL INFORMATION**

Event or facility: Enter the event name (for temporary shows) or the facility name (for permanent installations).

Customer: If the laser user is different from the applicant, fill in the "Customer" section; if not, enter "Same as applicant".

Site address: Street address, city, province or state.

GEOGRAPHIC LOCATION

Latitude and longitude: Be sure that latitude and longitude are specified in degrees, minutes and seconds. Some maps or devices may give this information in "Degrees. Decimal" form; this must be converted into degrees, minutes and seconds.

Ground elevation at site: This is the elevation in feet above Mean Sea Level, at the show site. It can be found on a topographic map or other resource.

Laser elevation above ground: If the laser is on a building or other elevated structure, enter the laser's height in feet above the ground.

Note.— For lasers on aircraft or spacecraft, attach additional information on the flight locations and altitudes.

DATE(S) AND TIME(S) OF LASER OPERATION

Testing and alignment: Enter the date(s) and time(s) during which testing and alignment procedures will take place.

Operation: Enter the date(s) and time(s) during which laser light will enter airspace.

2. **BRIEF DESCRIPTION OF OPERATION**

This should be a general overview. Specific laser configurations at the operation are described in detail using the Laser Configuration form on page 2. If necessary, attach additional pages.

3. **ON-SITE OPERATION INFORMATION**

Operator(s): List names and/or titles of operators.

On-site phones: There should be at least one working, direct phone link to the operator, or equivalent way of quickly reaching the operator (e.g. phoning to a central station that reaches the operator via radio). Two telephone numbers are listed on the form, so one can be used as an alternate or backup.

BRIEF DESCRIPTION OF CONTROL MEASURES
Describe the control measure(s) used to protect airspace; for example, termination on a building (where the beam path is not accessible by aircraft including helicopters), use of observers, use of radar and imaging equipment, physical methods of limiting the beam path, etc. The more that the operation relies on the control measures to ensure safety, the more detailed the description should be.

4. ATTACHMENTS

Number of laser configurations: List how many “Laser Configurations” you are submitting with this proposal. If a particular set-up operates with more than one laser, with different beam characteristics (power settings, pulse modes, divergence, etc.) or has multiple output devices (example: projector heads), then each should be analysed as a separate Laser Configuration using the form on page 2.

List additional attachments: You may need to add attachments such as maps, diagrams and details of control measures. Include whatever materials you feel are necessary to assist the Authority in sufficiently evaluating your proposal.

5. DESIGNATED CONTACT PERSON

This is the person whom the Authority will contact if additional information is needed. This should be the person with the most knowledge about laser safety at this operation. However, it could also be a central contact person who interfaces between the Authority and the laser operation personnel. The Designated Contact Person must work for or represent the applicant listed in the “From:” area at the top of the form.

STATEMENT OF ACCURACY
The Designated Contact Person should sign the form. However, in some cases the responsibility for the accuracy of the information may rest with another person, such as a Laser Safety Officer who is not acting as the contact. Therefore, the person who has the authority to bind the applicant must sign the form.

Appendix A

NOTICE OF PROPOSAL TO CONDUCT OUTDOOR LASER OPERATION(S)

NOTICE OF PROPOSAL TO CONDUCT OUTDOOR LASER OPERATION(S)

To: (NCAA)	From: (Applicant)	Report date:

1. GENERAL INFORMATION

Event or Facility	
Customer	Site address
GEOGRAPHIC LOCATIOON	

Latitude	*deg(º)*	*min (‘)*	*sec (“)*	Longitude	*deg(º)*	*min (‘)*	*sec (“)*

Ground elevation at site *(above Mean Sea Level)*	Laser elevation above ground *(if on buildings, etc.)*	Determined by: G GPS G Map G Other *(specify)*
DATES(S) AND TIME(S) OF LASER OPERATION		
Testing and alignment	Operation	

2. BRIEF DESCRIPTION OF OPERATION

3. ON-SITE OPERATION INFORMATION

Operation(s)	
On-Site phone #1	On-Site phone #2
BRIEF DESCRIPTION OF CONTROL MEASURES	

4. ATTACHMENTS

Number of laser configurations *[Fill out one copy of page 2 of this notice (“Laser Configuration”) for each configuration.]*
List any additional attachments needed to evaluate this operation *(could include maps, diagrams, and details of control measures).*

5. DESIGNATED CONTACT PERSON *(if further information is needed)*

Name	Position	
Phone	Fax	E-mail
STATEMENT ACCURACY To the best of my knowledge, the information provided in this Notice of Proposal is accurate and correct.		
Name *(if different from contact person)*	Position	
Signature	Date	

LASER CONFIGURATION

Fill out one copy of this form for each laser or laser configuration used at the Outdoor Laser Operations site.

---

1. CONFIGURATION INFORMATION

Name of event/facility	This page is configuration number______of ______	Report date
Brief description of configuration		

2. BEAM CHARACTERISTICS AND CALCULATIONS *(check one Mode of Operation only, and fill in only that column)*

Mode of Operation	[ ]Single pulse	[ ] Continuous wave	[ ] Repetitively pulsed
Laser Type *(lasing medium)*			
Power *Watts (W)*	*(not applicable)*	*Maximum power*	*Average power*
Pulse Energy *Joules (J)*		*(not applicable)*	
Pulse Width *Seconds (s)*		*(not applicable)*	
Pulse Repetition Frequency *Hertz (Hz)*	*(not applicable)*	*(not applicable)*	
Beam Diameter @ 1/e points *Centimetres (cm) (not mm)*			
Beam Divergence 1/e @ full angle *Milliradians (mrad)*			
Wavelength(s) *Nanometres (nm)*			
MAXIMUM PERMISSIBLE EXPOSURE (MPE) CALCULATIONS *(will be used to calculate NOHD)*			
MPE *W/cm^2*	*(not applicable)*		
MPE per pulse *J/cm^2*		*(not applicable)*	
VISUAL EFFECT CALCULATIONS *(will be used only for visible lasers to calculate SZED, CZED and LFED)*			
Pre-corrected Power (PCP) *Watts (W)*	Pulse Energy (J)*4	Maximum Power (from above)	Average Power OR Pulse Energy (J) x PRF (Hz)
Visual Correction Factor (VCF) *Enter "1.0" or use Table 5*			
Visually Corrected Power *PCP x VCF*			
3. BEAM DIRECTION(S)			
Azimuth *(degrees)* [ ] True	[ ] Magnetic	Magnetic variation *(degrees)*	
Minimum elevation angle *(degrees, where horizontal = 0°)*		Maximum elevation angle *(degrees)*	

4. DISTANCES CALCULATED FROM ABOVE DATA

(Fill in all three columns for NOHD. If a visible laser, fill in all three columns for SZED, CZED, and LFED.)

	Slant range *(ft)*	Horizontal distance *(ft)*	Vertical distance *(ft)*
NOMINAL OCULAR HAZARD DISTANCE			
NOHD *(based on MPE)*			
VISUAL EFFECT DISTANCES If the laser has no wavelengths in the visible range (400–700 nm), enter "N/A (non-visible laser)" in all blocks below. For visible lasers, if the calculated visual effect distance is less (shorter distance) than the NOHD, you must enter "Less than NOHD".			
SZED *(for 100 µW/cm2 level)*			
CZED *(for 5 µW/cm2 level)*			
LFED *(for 50 nW/cm2 level)*			

5. CALCULATION METHOD

[ ] Commercial software (print product name)	[ ] Other [describe method (spreadsheet, calculator, etc.)]

Appendix B

SUSPECTED LASER BEAM INCIDENT REPORT AND SUSPECTED LASER BEAM EXPOSURE QUESTIONNAIRE

This form may be used by local ATC or airline authorities to report a suspected laser beam exposure. When completed, the report should be forwarded to the NCAA as soon as possible for further investigation.

Name______________________________________Age ______________________

Position (pilot, co-pilot, controller, etc.)________________Phone ______________________

Type of vision correction worn at time of incident (spectacles/contact lenses) ________________

Type of aircraft ____

Aircraft ID or call ____

Date and time of incident (UTC) __________________________________

Date and time report is being completed (UTC) ______________________

Environmental factors:

Weather conditions ____

VMC/IMC ____

Ambient light level (day, night, sunlight, dawn, dusk, starlight, moonlight, etc.) ______________

____

Location of incident

Near (aerodrome/city/NAVAID) ____________________________________

Radial and distance ____

Phase of flight ____

Type/name of approach or departure procedure ______________________

Heading/approximate heading if in turn _____________________________

Altitude (AGL)____________________(MSL) _________________________

Aircraft bank and pitch angles_____________________________________

Angle of incidence

Did the light hit your eye(s) directly or from the side? ________________________

Light description:

Colour____

Nature of beam (constant/flicker/pulsed) ______________________________

Light source (stationary or moving) ________________________________

Do you feel you were intentionally tracked? ______________________________

Relative intensity (flashbulb, headlight, sunlight) __________________________

Duration of exposure (seconds) __________________________________

Was the beam visible prior to the incident? ______________________________

____

Circle the window where the light entered the cockpit:

Left left-front centre right-front right other ___________________________

Elevation of the beam from horizontal (degrees) ___________________________

Effect on individual

Describe visual*/psychological/physical effects ____________________________

____

____

Duration of visual effects (seconds/minutes/hours/days) ______________________

Do you intend to seek medical attention? ________________________________

____

Note.— This is recommended if even minor symptoms were experienced.

Effect on operational or cockpit procedures: ______________________________

____

____

* Examples of common visual effects:

After-image. An image that remains in the visual field after an exposure to a bright light.

Blind spot. A temporary or permanent loss of vision of part of the visual field.

Flash-blindness. The inability to see (either temporarily or permanently) caused by bright light entering the eye and persisting after the illumination has ceased.

Glare. A temporary disruption in vision caused by the presence of a bright light (such as an oncoming car's headlights) within an individual's field of vision. Glare lasts only as long as the bright light is actually present within the individual's field of vision.

SUSPECTED LASER BEAM EXPOSURE QUESTIONNAIRE

This questionnaire may be filled out by the NCAA during interviews with persons exposed to laser beams. This information will be used to aid in any subsequent investigation and provide important medical and statistical data for the review of regulatory and enforcement issues associated with new laser beam applications and threats to aviation safety. The completed form should be forwarded to the appropriate aviation authority as soon as possible.

1. Did anyone else see the light beam? ____
2. What was the colour(s) of the light? ____

   Did the colour(s) change during the exposure? ____
3. Did the light come on suddenly, and did it become brighter as you approached it? ______________

   ____
4. Was the light continuous or did it seem to flicker? _______________________________________

   If it flickered, how rapidly and regularly? ____
5. Did the light fill your cockpit or compartment? ____
6. How would you describe the brightness of the light? ____________________________________

   Was it equally bright in all areas or was it brighter in one area? ___________________________
7. Did you attempt an evasive manoeuvre? ____

   If so, did the beam follow you as you tried to move away? _______________________________

   How successful were you in avoiding it? ____
8. Do you know the source of the light emission? ____
9. Can you estimate how far away the light source was from your location? ____________________

   Was the source moving? ____
10. What was between the light source and your eyes — windscreen, glasses, contact lenses, etc.? ____

    Did any of these sustain damage by the light? ____
11. Was the light coming directly from its source or did it appear to be reflected off other surfaces? ____

    ____

    Were there multiple sources of light? ____
12. Did you look straight into the light beam or off to the side? ___________________________
13. How long was the exposure? ____

    Did the light seem to track your path or was there incidental contact? ______________________
14. At what time of the day did the incident occur? ______________________________________

15. What was the visibility? ____

What were the atmospheric conditions — clear, overcast, rainy, foggy, hazy, sunny? ____________

16. What tasks were you performing when the exposure occurred? ______________________________

Did the light prevent or hamper you from doing those tasks, or was the light more of an annoyance?

____

17. What were the visual effects you experienced (after-image, blind spot, flash-blindness, glare*)? ____

____

18. How long did any symptoms you experienced from the exposure last? _______________________

Are any symptoms (tearing, light sensitivity, headaches, etc.) still present? ____________________

19. Did you touch or rub your eyes at the time of the incident? ________________________________

20. Did you have your eyes examined after the incident? _____________________________________

If so, when and by whom? ____

What were the results of this visit? ____

21. Did you report the incident? ____

If so, to whom (ATC, medical personnel, safety officer, etc.) and when? _______________________

* Examples of common visual effects:

After-image. An image that remains in the visual field after an exposure to a bright light.

Blind spot. A temporary or permanent loss of vision of part of the visual field.

Flash-blindness. The inability to see (either temporarily or permanently) caused by bright light entering the eye and persisting after the illumination has ceased.

Glare. A temporary disruption in vision caused by the presence of a bright light (such as an oncoming car's headlights) within an individual's field of vision. Glare lasts only as long as the bright light is actually present within the individual's field of vision.

Appendix C

AMSLER GRID TESTING PROCEDURE

The Amsler grid test is designed to detect defects in the central visual field of an eye, corresponding to retinal lesions as small as 50 micrometres.

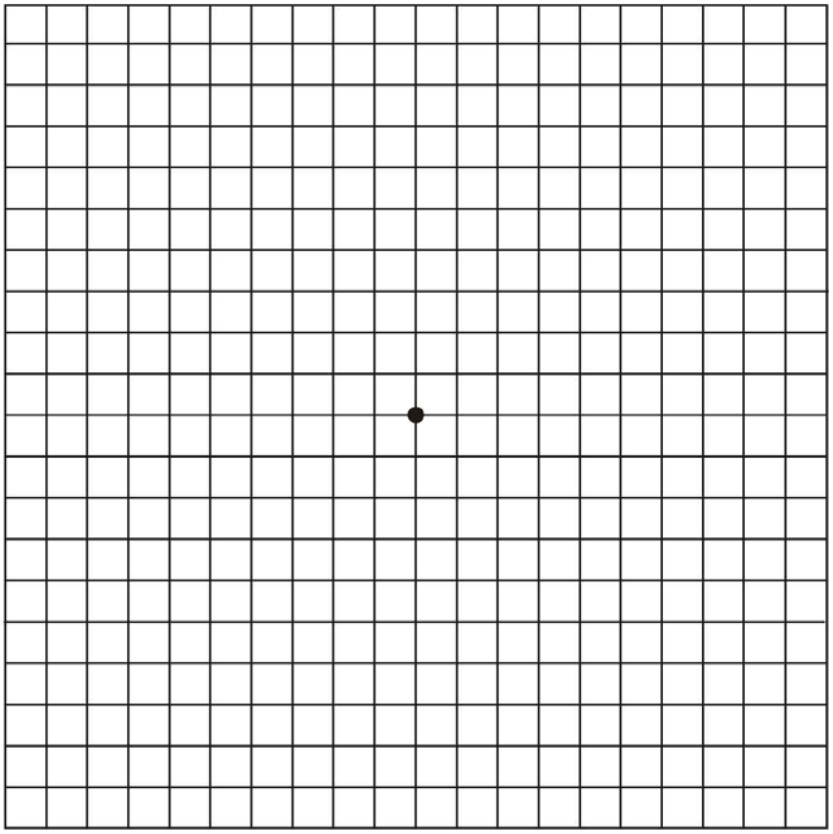
The chart below is sized to be viewed at a distance of 28–30 cm, the usual distance for reading tests. At this distance the test will examine the central 20 degrees of the patient’s field of vision for abnormalities, with each small square equivalent to 1 degree. Before using this chart:

a) the refraction of the eye in question must be exactly corrected for this distance;

b) the chart must be clearly and evenly illuminated as for a reading test;

c) all artificial mydriasis and any ophthalmoscopy immediately before the examination must be avoided; and

d) the other eye should be covered, preferably with an occluder.



While continually urging the patient to look steadily upon the central point, ask the following questions. Record the responses and ask the patient to carefully draw any abnormal results on the grid chart.

1. Do you see the spot in the centre of the square chart?
2. Keeping your gaze fixed upon the spot in the centre, can you see the four corners of the big square? Can you also see the four sides of the square? In other words, can you see the whole square?
3. Keeping your gaze fixed upon the spot in the centre, do you see the network intact within the whole square? Are there any interruptions in the network of squares, such as holes or spots? Is it blurred in any place? If so, where?
4. Keeping your gaze fixed upon the spot in the centre, are both the horizontal and vertical lines straight and parallel? In other words, is every small square equal in size and perfectly regular?
5. Keeping your gaze fixed upon the spot in the centre, do you see any movement of certain lines? Is there any vibration or wavering, shining or colour tint? If so, where?
6. Keeping your gaze fixed upon the spot in the centre, at what distance from this point do you see the blur or distortion? How many small intact squares do you find between the blur or distortion and the centre point where your gaze is fixed?

APPENDIX D

1.0 GLOSSARY

Note.— *The definitions of the terms listed below are based on a pragmatic approach. The terms defined are therefore limited to those actually used in this manual. This listing is not intended to constitute a dictionary of terms used in the laser field as a whole.*

Absorption. Transformation of radiant energy to a different form of energy (usually heat) by interaction with matter.

Accessible emission limit (AEL). The maximum accessible emission power or energy permitted within a particular laser class.

Accessible radiation. Optical radiation to which the human eye or skin may be exposed in normal usage.

Actinic radiation. Electromagnetic radiation in the visible and ultraviolet part of the spectrum capable of producing photochemical changes.

Aerodrome reference point (ARP). The designated geographical location of an aerodrome.

After-image. An image that remains in the visual field after an exposure to a bright light.

Attenuation. The decrease in the laser beam power or energy as it passes through an absorbing or scattering medium.

Average power. The total energy imparted during exposure divided by the exposure duration.

Aversion response. Closure of the eyelid or movement of the head to avoid an exposure to a noxious stimulant or bright light. In laser safety standards, the aversion response (including blink reflex time) is assumed to occur within 250 milliseconds (0.25 s).

Beam. A collection of rays that may be parallel, divergent or convergent.

Beam diameter. For the purpose of this manual, the beam diameter is the radial distance across the centre of a laser beam where the irradiance is 1/e times the centre-beam irradiance (or radiant exposure for a pulsed laser).

Beam waist. The minimum dimension of a cross section of the beam.

Buffer angle. An angle added to the beam divergence or intended laser projection field in order to ensure a protection zone.

Buffer zone. A volume of air surrounding the laser beam, all potential locations of the laser beam and all hazardous diffuse or specular reflections, where the maximum permissible exposure (MPE) or visual interference levels are exceeded. It includes the beam divergence or scanning extent of the laser beam plus the buffer angle and the full range of the laser beam to the point where the MPE or any applicable visual interference level is not exceeded. Natural terrain or beam masks may truncate part of this volume.

Cavity. The optical assembly of a laser usually containing two or more highly reflecting mirrors which reflect radiation back into the active medium of the laser.

Collateral radiation. Any electromagnetic radiation emitted by a laser, except the laser beam itself, which is necessary for the operation of the laser emitter or is a consequence of its operation.

Collimated beam. A beam of radiation with very low divergence or convergence and therefore effectively considered parallel.

Continuous wave (CW). The output of a laser which is operated in a continuous rather than a pulsed mode. In laser safety standards, a laser operating with a continuous output for a period greater than 0.25 s is regarded as a CW laser.

Critical level. The minimum effective irradiance from a visible laser beam which can interfere with critical task performance due to transient visual effects.

Diffraction. Deviation of part of a beam, determined By the wave nature of radiation and occurring when the radiation passes the edge of an opaque obstacle.

Diffuse reflection. The component of a reflection from a surface which is incapable of producing a virtual image such as is commonly found with flat finish paints or rough surfaces. A matt surface will reflect the laser beam in many directions. Viewing a diffuse reflection from a matt surface may produce either a small or a large retinal image, depending on the viewer distance and the size of the illuminated surface.

Divergence (ϕ). For the purpose of this manual, the divergence is the increase in the diameter of the laser beam with distance from the exit aperture, based on the full angle at the point where the irradiance (or radiant exposure for pulsed lasers) is 1/e times the maximum value.

Electromagnetic radiation. The flow of energy consisting of orthogonally vibrating electric and magnetic fields. Electromagnetic radiation includes optical radiation, X-rays and radio waves.

Electromagnetic spectrum. The range of frequencies or wavelengths over which electromagnetic radiations are propagated. The spectrum ranges from short wavelengths, such as gamma rays and X-rays, through visible radiation to longer wavelength radiations of microwaves, and television and radio waves.

Energy. The capacity for doing work. Energy content is commonly used to characterize the output from pulsed lasers and is generally expressed in joules (J).

Excited state. The state of an atom or molecule when it is in an energy level with more energy than in its normal or “ground” state.

Exposure duration. The duration of a pulse or a series or a train of pulses, or of continuous emission of laser radiation incident upon the human body.

Flash-blindness. The inability to see (either temporarily or permanently) caused by bright light entering the eye and persisting after the illumination has ceased.

Free radical. An atom or group of atoms in a transient chemical state containing at least one unpaired electron. Free radicals may be produced within or introduced into biological tissue where they may cause damage.

Gaussian beam profile. The bell-shaped profile of a laser beam when the laser is operating in the simplest mode.

Glare. A temporary disruption in vision caused by the presence of a bright light (such as an oncoming car’s headlights) within an individual’s field of vision. Glare is unassociated with biological damage and lasts only as long as the bright light is actually present within the individual’s field of vision.

Hazard. Something with the potential to cause harm to people, property or the environment.

Hazard zone. The space within which the level of radiation during operation of a laser emitter exceeds the applicable exposure limit. See also nominal hazard zone (NHZ).

Infrared radiation. For the purpose of this manual, electromagnetic radiation with wavelengths that lie within the range 700 nm to 1 mm.

Instrument flight rules (IFR). A set of rules governing the conduct of flight under instrument meteorological conditions.

Interlock. See safety interlock.

Invisible laser beam. A laser emission with a wavelength either shorter than 400 nm or longer than 700 nm. Laser sources near these defining limits may be capable of producing a visual stimulus.

Irradiance (E). The power per unit area, expressed in watts per square centimetre (W/cm^2) or watts per square metre (W/m^2).

Laser. 1) An acronym for light amplification by stimulated emission of radiation. 2) A device that produces an intense, coherent, directional beam of optical radiation by stimulating emission of photons by electronic or molecular transitions to lower energy levels.

Laser-beam critical flight zone (LCFZ). See protected flight zones a).

Laser-beam free flight zone (LFFZ). See protected flight zones b).

Laser-beam free level. The maximum level of visible optical radiation which is not expected to cause any visual interference to an individual performing critical tasks.

Laser-beam sensitive flight zone (LSFZ). See protected flight zones c).

Laser emitter. Same as laser 2).

Laser safety officer (LSO). An individual who is knowledgeable in the evaluation and control of laser hazards and has responsibility for oversight of the control of those hazards.

Laser source. Seesource.

Light (visible radiation). A form of electromagnetic radiation capable of producing a visual stimulus to the human eye. Its wavelength range is approximately from 400 nm to 700 nm (between ultraviolet and infrared). Laser sources of an equivalent power slightly outside this range may be capable of producing less intense visual stimuli.

Limiting aperture (Df). The diameter of a circle over which irradiance or radiant exposure is averaged for comparison to the maximum permissible exposure (MPE).

Local laser working group (LLWG). A group, convened to assist in evaluating the potential effect of laser emissions on aircraft operators in the vicinity of the proposed laser activity. Participants may include, but are not limited to, representatives from the aerodrome tower, area control centre, aerodrome management, airspace users, local officials, military representatives, qualified subject experts, laser manufacturers and the laser proponent.

Maximum permissible exposure (MPE). The internationally accepted maximum level of laser radiation to which human beings may be exposed without risk of biological damage to the eye or skin.

Mitigation. Use of control measures aimed at neutralizing the effect of laser beams on flight safety.

Nominal hazard zone (NHZ).The space within which the level of the direct, reflected or scattered radiation during operation of a laser emitter exceeds the applicable maximum permissible exposure (MPE). Exposure levels beyond the boundary of the NHZ are below the applicable MPE level.

Nominal ocular hazard distance (NOHD). The distance along the axis of the laser beam beyond which the appropriate maximum permissible exposure (MPE) is not exceeded (i.e. an indication of the “safe viewing” distance). An equivalent term for skin exposure is “skin

hazard distance”.

Normal flight zone (NFZ). See protected flight zones d).

Optical density (OD). A physical property of a material that quantifies the attenuation of the laser beam.

Optical radiation. Part of the electromagnetic spectrum comprising infrared, visible and ultraviolet radiations.

Photon. In quantum mechanics, the smallest particle of optical radiation.

Pointing accuracy. The maximum angle of expected error in beam direction during all projected uses of the laser emitter.

Population inversion. The condition needed for light amplification to occur whereby the number of atoms in an excited state is greater than the number of atoms in a lower energy state.

Power. The rate at which energy is emitted, transferred or received. Unit: watts (joules per second).

Proponent. The legal entity (corporation, company, individual) applying to conduct an outdoor laser operation at a specific time and location.

Protected flight zones. Airspace specifically designated to mitigate the hazardous effects of laser radiation.

a) **Laser-beam critical flight zone (LCFZ).** Airspace in the proximity of an aerodrome but beyond the laser-beam free flight zone (LFFZ) where the irradiance is restricted to a level unlikely to cause glare effects.

b) **Laser-beam free flight zone (LFFZ).** Airspace in the immediate proximity to the aerodrome where the irradiance is restricted to a level unlikely to cause any visual disruption.

c) **Laser-beam sensitive flight zone (LSFZ).** Airspace outside, and not necessarily contiguous with, the LFFZ and LCFZ where the irradiance is restricted to a level unlikely to cause flash-blindness or afterimage effects.

d) **Normal flight zone (NFZ).** Airspace not defined as LFFZ, LCFZ or LSFZ but which must be protected from laser radiation capable of causing biological damage to the eye.

Pulsed laser. A laser that delivers its energy in individual pulses lasting less than 0.25 s. See repetitively-pulsed laser.

Pulse duration. The duration of a laser pulse, usually measured as the time interval between the half-power points on the leading and trailing edges of the pulse.

Pulse repetition frequency (PRF). The number of pulses that a laser produces over an applicable time frame divided by that time frame. For uniform pulse trains lasting over 1 s, the PRF is the number of pulses emitted by the laser in 1 s. Unit: hertz (Hz).

Radian. A unit of angular measure equal to the subtended angle at the centre of a circle by an arc whose length is equal to the radius of the circle. 1 radian = 57.3 degrees; 2πradians = 360 degrees.

Radiant energy (Q). Energy emitted, transferred or received as radiation. Unit: joule (J).

Radiant exposure (H). The laser beam energy per unit area, expressed in joules per square centimetre (J/cm^2) or joules per square metre (J/m^2).

Radiant power (Φ). Power emitted, transferred or received as radiation. Unit: watt (W).

Reflection. Deviation of radiation following incidence on a surface. A reflection can be either diffuse or specular. See diffuse reflection and specular reflection.

Refraction. The redirection of light as it passes from one medium to another.

Repetitively-pulsed laser. A laser producing multiple pulses of radiant energy occurring in sequence with a pulse repetition frequency (PRF) greater than 1 Hz.

Retinal hazard region. Wavelengths between 400 nm and 1400 nm.

Safety interlock. 1) A device which is activated upon entry to a laser laboratory or enclosure, which terminates laser operation or reduces personnel exposure to below the maximum permissible exposure (MPE). 2) A device that is activated upon removal of the protective housing of a laser in such a way as to prevent exposure above the maximum permissible exposure (MPE).

Scanning laser beam. Laser radiation that moves, i.e. has a time-varying direction, source or pattern of propagation with respect to a stationary frame of reference.

Scintillation. Rapid changes in irradiance levels in a crosssection of a laser beam, caused by variations of the index of refraction in a medium as a consequence of temperature and pressure fluctuations.

Sensitive level. The minimum effective irradiance from a visible laser beam, which can cause temporary vision impairment and therefore interfere with performance of vision-dependent tasks. Illumination at this level may cause after-images or flash-blindness.

Source. A laser emitter or a laser-illuminated reflecting surface.

Specular reflection. A mirror-like reflection that usually maintains the directional characteristics of a laser beam.

Terminated beam. An output from a laser which is directed into airspace but is confined by a suitable object that blocks the beam or prohibits the continuation of the beam at levels capable of producing psychological effects or visual disruption.

Transmission. Passage of radiation through a medium. If not all the radiation is absorbed, that which passes through is said to be transmitted.

Ultraviolet radiation. Electromagnetic radiation with wavelengths shorter than those of visible radiation, for the purpose of this manual: 180 to 400 nm.

Vestibular apparatus. The organ of equilibrium in the inner ear. Because of its complicated anatomy, it is also called the labyrinth. It consists of the semicircular canals and the otolith organs.

Visible radiation. See light.

Visual flight rules (VFR). A set of rules governing the conduct of flight under visual meteorological conditions.

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2.0 LIST OF ABBREVIATIONS, SYMBOLS AND UNITS

ADI	attitude direction indicator
AEL	accessible emission limit
AGL	above ground level
ANSI	American National Standards Institute
ARP	aerodrome reference point
ATC	air traffic control
ATIS	automatic terminal information service
CIE	International Commission on Illumination (Commission Internationale de l’Éclairage)
CW	continuous wave
CZED	critical zone exposure distance
D_f	limiting aperture
DME	distance measuring equipment
FAA	Federal Aviation Administration
FDA	U.S. Food and Drug Administration
FLIR	forward looking infrared
FSEL	flight safe exposure limits
H	radiant exposure
HSI	horizontal situation indicator
HUD	head-up display
Hz	hertz
IFR	instrument flight rules
ILS	instrument landing system
IMC	instrument meteorological conditions
IR	infrared
J	joule
λ	wavelength
laser	light amplification by stimulated emission of radiation
LCFZ	laser-beam critical flight zone
LED	light emitting diode
LEP	laser eye protection
LFED	laser free exposure distance
LFFZ	laser-beam free flight zone
LIDAR	light detection and ranging
LLWG	local laser working group
LSA	loss of situational awareness
LSFZ	laser-beam sensitive flight zone
LSO	laser safety officer
MFD	multifunction display
MIL	maximum irradiance level
MOVL	minimal ophthalmoscopically visible lesion
MPE	maximum permissible exposure

mrad	milliradian
MSL	mean sea level
navaid	aid to air navigation
Nd:YAG	neodymium yttrium-aluminium-garnet
NFZ	normal flight zone
NHZ	nominal hazard zone
NIR	near infrared
nm	nanometre
NM	nautical mile
NOHD	nominal ocular hazard distance
NOTAM	notice to airmen
NSHD	nominal sensitivity hazard distance
NVD	night vision device
NVG	night vision goggles
OD	optical density
PCP	pre-corrected power
φ	beam divergence
Φ	radiant power
PRF	pulse repetition frequency
Q	radiant energy
SAE	Society of Automotive Engineers
SD	spatial disorientation
SIAP	standard instrument approach procedure
STAR	standard terminal arrival route
SZED	sensitive zone exposure distance
TVI	temporary visual impairment
TVL	temporary vision loss
UTC	coordinated universal time
UV	ultraviolet
VCF	visual correction factor
VCP	visually corrected power
VED	visual effect distance
VFR	visual flight rules
VMC	visual meteorological conditions
W	watt
YAG	yttrium-aluminium-garnet