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Outdoor Laser Operations in the Navigable Airspace

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Abstract

This document has been prepared by the Safety Regulation Commission. It is intended to assemble information available from different sources in a reference for its possible use by ATM safety regulatory bodies in dealing with specific situations.

This document does not provide technical standards or regulations but only an introduction to this subject matter as well as information resulting from a review of current developments and methodologies.

Keywords

Laser	Safety Occurrences	Key Risk Areas	Unwanted illumination
Control Measures			

CONTACT PERSON :	Juan Vázquez	**TEL:** +32 2 729 4681	**DIVISION:** DGOF/SRU

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The following table identifies all authorities who have successively approved the present issue of this document.

AUTHORITY	NAME AND SIGNATURE	DATE
Head Safety Regulation Unit (SRU)	(Peter STASTNY)	14.02.2001
Chairman Safety Regulation Commission (SRC)	(Philip S. GRIFFITH)	14.02.2001

DOCUMENT CHANGE RECORD

The following table records the complete history of the successive editions of the present document.

EDITION	DATE	REASON FOR CHANGE	SECTIONS PAGES AFFECTED
0.01	12 Oct. 2000	First working draft prepared by SRU.	All
0.02	15 Jan. 2001	Draft incorporating modifications after SRU review and formal consultation with FAA, SAE, Transport Canada and UK DAP.	All
1.0	14 Feb. 2001	Definition of CW laser included in accordance with comments made at SRC10. Released Issue.	Appendix A

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SAFETY REGULATION COMMISSION DOCUMENT

Outdoor Laser Operations in the Navigable Airspace

1. INTRODUCTION

1.1 Background

At its meeting held in February 2000, the EUROCONTROL Safety Regulation Commission (SRC) noted the use of lasers in outdoor light shows, as well as in other activities, as a potential source of hazard to aircraft operations near airports and other sensitive navigable airspace areas. SRC also concluded that this was a new problem to take into account by ATM safety regulators in order to avoid unwanted laser illuminations during air operations. It was also decided to produce a document presenting the current existing approaches to this issue as a practical means to contribute to the awareness on this matter.

In the last years, outdoor laser shows and tests have proliferated. These activities make use of a generated light source to produce intense and directional beams of light and create special lighting effects. The nature of those visual effects has made lasers increasingly popular for entertainment uses. While these shows are spectacular, some are located near commercial airports. This has created a potential hazard to aircraft operations since several aircrew laser illuminations have been reported. We can expect these trends to continue as laser technology advances, costs decrease and the technology becomes more readily available.

Outdoor lasers produce an intense, coherent, directional beam of light with wavelengths covering the visible spectrum of 400-700 nm. Their concentrated energy creates not only the potential for permanent eye injury to pilots, crew and passengers, but also loss of night vision. When laser beams are projected or reflected into airspace and intercept aircraft, unplanned exposure (incidents of illumination, startle and glare) may cause pilot distractions or create temporary vision impairments (flashblindness, afterimage). These effects may pose significant flight safety hazards in critical phases of flight, in particular during approach and landing operations in close proximity to airports.

1.2 Possible key risk area

The US Society of Automotive Engineers (SAE) was requested by the FAA to assist in developing a FAA Order on this issue as well as an associated FAA Advisory Circular. Accordingly, the SAE developed an airspace standard (AS 4970 - Human Factors Considerations for Outdoor Laser Operations in the Navigable Airspace) published in December 1999. The document provides a systematic method of protecting navigable airspace from unwanted laser illuminations. Within the SRC, the existence of this initiative raised the question of whether this was a major safety concern in the ECAC area.

Normally, the number of reported incidents would determine whether this would be classified as a key risk area, with mitigation action necessary. However, reporting schemes which could provide classification of such occurrences are not widely in place in the ECAC area. SRC initiated some actions to determine whether a specific regulatory harmonised response was needed. In particular Member States were invited to provide inputs on this issue.

1.3 Initial review of the situation

Since a significant number of States' inputs were received, it was made clear that there was a considerable interest in preventing possible problems related with this new topic, and that this was a new safety issue to take into account. Certain States declared that outdoor lasers were already considered as a significant safety concern. Some regulators reported the use of ad-hoc procedures or arrangements to deal with events of this sort. At the same time, others seem to have no problems with this specific matter.

The scope of the problem seems to vary between States. This is a clear indication that the issue is a matter to be locally considered since it concerns local scenarios where outdoor laser activities take place. Therefore, SRC concluded that no harmonised safety regulatory requirements were to be developed. At this stage, ATM safety regulators may successfully address the issue within their national frameworks.

Nevertheless, the survey revealed that some incidents have been reported in the ECAC region. Some specific methods have been considered by particular national bodies to address the problem. Accordingly, SRC decided to disseminate the available information on this issue. Co-ordinating actions for the exchange and dissemination of information may improve the awareness on this problem helping regulators in dealing with it.

1.4 Purpose, sources and limitations

The purpose of this SRC Document is to assemble information available from different sources in a reference for its possible use by regulatory bodies in dealing with specific situations. This SRC Document does not provide technical standards to be used but only an introduction to the matter and guidance resulting from a review of some existing methodologies.

This document has been prepared by the SRU. It relies significantly on inputs received as a result of a request, dated January 2000, sent to SRC members, advisers and observers in order to review the current situation. In addition, specific papers and documents have been searched and collated by SRU. Topic and word based searches of the World Wide Web also provided complementary inputs.

At present most countries have no specific regulations governing the use of outdoor lasers in the navigable airspace, however, some documents do exist which provide valuable input in this area. Most are linked with current initiatives taking place in the United States and Canada, mainly through SAE, FAA and Transport Canada, to establish regulations and standards for the operation of outdoor lasers and other directed bright light sources.

Within the ECAC region, the United Kingdom has also produced some specific material offering a simple but effective approach to deal with outdoor lasers in various situations.

ICAO has set up a Study Group to develop SARPS regarding the use of outdoor lasers. The Group has already submitted initial proposals for ICAO approval, and a final document might be released by the end of 2001. The standards proposed are in accordance with the North American model which does require a specific approach in dealing with outdoor lasers.

It should be noted that this SRC Document is not intended to propose a new approach or a particular existing method to deal with outdoor lasers. The document presents and collects available information to improve the awareness on possible options to be assessed and implemented at a national or local level. It is the responsibility of individual national designated authorities to define and implement mitigation measures whenever necessary in dealing with outdoor laser hazards.

The different documents and sources reviewed by the SRU are referenced in a specific appendix to this paper.

2. REVIEW OF EXISTING METHODS

2.1 Possible approaches

From a safety point of view, the main objective of any possible approach is to provide a systematic method for protecting the navigable airspace from unwanted laser illuminations. Normally, this will involve procedures to gain approval from regulatory agencies for laser operations conducted within particular volumes of airspace.

Until now, two different ways have normally been considered to deal with outdoor laser operations:

a) Through ad hoc approaches based on already existing procedures to tackle similar situations and problems;

b) Using a specific approach derived from a detailed study of the issue.

2.2 Ad hoc approach

Regulation on outdoor laser operations might be fitted into existing procedures and arrangements already established to mitigate risks associated with other well known activities (fireworks, lighthouses, searchlights, especial events) that also may affect the navigable airspace.

These procedures may provide an initial framework. After introducing appropriate modifications, they might be used to deal with lasers as new and isolated events where the activity has not proliferated widely. However, it should be noted that several assumptions could exist behind this kind of approach. Hazards associated with outdoor lasers have their own particularities, and differences should be specifically considered.

2.3 Evolving towards a specific approach

As laser operations proliferate around sensitive airspace areas, it becomes clear that a specific study may determine appropriate criteria to establish special procedures and rules to address the issue. Specifically designed procedures could clearly be managed in parallel with those handling other special events (fireworks, lighthouses, etc). However, the determination of applicable mitigation measures will follow a specific methodology derived from the analysis of hazards created by outdoor lasers.

Current initiatives, by some countries, are intended to define, through specific analysis of outdoor laser hazards, methods for protecting the navigable airspace from unwanted illuminations. These methods will be the basis for procedures to seek approval from regulatory agencies for operations of various classes of laser devices and their applications within this volume of airspace.

The SAE standard AS 4970 is an essential contribution in this area. The specialised SAE committee SAE G 10 has met over 30 times during four years with different agencies to identify the issues, technologies, and operational capabilities of outdoor laser operations in navigable airspace. This information was initially requested by the FAA to assist in developing FAA Order 7400.2 and an associated FAA Advisory Circular.

The SAE standard has provided an essential reference not only for the FAA and Transport Canada, but also for an ICAO study group established to develop SARPS on this subject. The group has completed their work and the resulting proposals have been submitted for ICAO approval. A final document might be released by the end of 2001. The standards proposed require a specific approach in dealing with outdoor lasers. The main elements under consideration are already included in the existing methods adopted by FAA and Transport Canada in the light of SAE studies.

Within the ECAC area, the UK has successfully used an approach based on non-regulatory guidelines to provide useful guidance and educate the entertainment industry about the need to inhibit and notify laser activities. This alternative approach has offered specific but simple methods to provide protection against unwanted illuminations around aerodromes.

2.4 Aspects on Outdoor Laser Operations

The review of existing methods suggests five main issues to be addressed throughout the rest of this document:

- Establishment of formal procedures to seek approval from regulatory agencies
- Principles of a laser safety analysis methodology for aircraft operations
- Navigable airspace control measures
- Pilot procedures
- Reporting safety occurrences involving outdoor laser operations

3. ESTABLISHMENT OF FORMAL PROCEDURES

The most developed approaches propose a formal approval in order to authorise the use of outdoor laser uses that could affect aircraft operations.

It should be noted that in some countries health or radiological control authorities currently regulate the use of outdoor lasers. Co-ordination with involved agencies or bodies may be necessary. In any case, designated national aviation authorities should be in a clear position to determine the conditions of use of outdoor lasers in relation with their responsibilities concerning the safe and efficient use of airspace by civil aviation.

Depending upon national arrangements, military laser applications and research laser applications may be exempt from general regulations, but subject to specific military regulations or other applicable rules.

3.1 Basic regulatory principles

As an example of specific statements to be included within applicable regulations, the Canadian Notice of Proposed Amendment[1] NPA 99-145 to CAR 601 may provide the following basic regulatory principles:

> ***"No person shall project, or cause to project, a laser or other directed light source at an aircraft in such a manner as to create a hazard to aviation safety, damage to the aircraft, or injury to persons on board that aircraft."***
>
> ***"Any person planning to use, or using, a directed bright light source outdoors in such a manner that the light source may be projected into navigable airspace with sufficient power to create a hazard to aviation safety shall provide written notification to the Minister before the use."***

Similar regulatory statements could form the basis on which approval procedures can be derived. The main objective of such procedure will be the determination of conditions for the use of outdoor lasers in a specific place and context. The procedure has to be intended to facilitate the analysis of the effects the laser may create upon nearby navigable airspace.

3.2 Possible procedures:

The FAA approach may provide the basic elements of such procedures as developed in an Advisory Circular. The FAA Advisory Circular covers the following aspects:

- Applicability: establishing that any proponents planning to conduct laser operations in the navigable airspace should file notice with the FAA;
- Submission: FAA Advisory Circular establishes that the notice has to be submitted at least 30 days before the activity takes place;

[1] *The Canadian NPA is currently undergoing further review and is still subject to change.*

- Information to be submitted;

- Actions to be taken by FAA regarding the submitted information, to conduct an aeronautical study to evaluate the effects and delivering an appropriate response to the proponent.

3.3 Information to be provided:

SAE AS4970 proposes some examples of forms to be used by proponents in seeking approval by proponents to conduct outdoor laser operations. Through the Advisory Circular, the FAA adopts quite similar models. Included with the forms are detailed instructions which provide extensive guidance on calculations to be made and form completion.

The proponent would be asked to provide information about the activity. This clearly concerns some basic data:

- Geographic location; date and time of operation
- Description of the operation
- On-site operation information

In addition, a *Laser Configuration Worksheet* is requested as part of the notification presented to the regulatory agency and provides detailed information on:

- Beam characteristics and calculations
- Maximum permissible exposure calculations
- Visual effect calculations
- Beam directions
- Distances calculated from above data

It should be noted that, within this approach, basic calculations are to be carried out by the proponent in accordance with the instructions included with the forms. Clear guidance has to be provided including applicable definitions, equations, detailed steps for calculations, equations, etc. The designated regulatory agency will use this information to determine the effects on users of the navigable airspace taking into account specific aviation aspects.

3.4 Arrangements not based on specific requirements

In some countries, arrangements already in place are not currently based on regulatory requirements but on written guidelines to address the issue.

That approach has proved successful in the UK. In 1997, in response to the increasing number and variety of light displays, and the lack of any kind of guidance to the entertainment industry or airports, the UK Directorate of Airspace Policy (DAP) produced a set of Guidelines aimed at reducing the potential hazard to aviation in the vicinity of airfields. These were non-regulatory and sought to educate the entertainment industry about the need to inhibit and notify laser activities near airfields in particular, and elsewhere if appropriate; they also included a reminder about existing legislation on endangering aircraft and dangerous lights. The Guidelines were then forwarded to all civil and military airfields and to entertainment associations for onward relay to their members.

The Guidelines for Outdoor Lasers, Searchlights and Fireworks issued in July 1998 by the UK Directorate of Airspace Policy, establishes that:

- The event organiser should notify the appropriate bodies of the activity, and provide enough information about the event, including the time, duration and intensity, with at least 28 days notice of the event.

- If the event organisers decline to accept professional advice to cancel the event, they should be advised that action could be taken against them under the existing laws in accordance with some generic articles not currently developed in the form of specific requirements.

The UK Guidelines have been kept deliberately uncomplicated, and this advisory approach, with the implicit threat of prosecution under existing legislation has demonstrated to be effective within the UK context. The response by the British entertainment industry has been generally positive, and 1999 saw the notification and subsequent promulgation of 88 laser displays.

4. PRINCIPLES OF A LASER SAFETY ANALYSIS METHODOLOGY

Several aspects have to be considered and balanced to evaluate outdoor laser operations in their particular context.

As risk increases, stronger mitigation measures will have to be implemented. The SAE has proposed a Laser Safety Analysis Methodology as a basis for specific analysis activities. This methodology is intended to identify risks depending on several factors in order to assist in defining the types and levels of protection required.

The SAE Laser Safety Analysis Methodology consists of seven successive steps:

4.1. First Step - Determination of operational volume and hazard distances:

In order to perform an assessment, the actual spatial volume of operation and power levels of the laser must be determined. In practical terms, this can be done identifying hazard distances.

SAE AS4970 provides definitions for the hazard distances to be calculated. Equations and practical examples are also included. There are three essential distances to consider:

- *Nominal Ocular Hazard Distance (NOHD):*
  The beam is an eye hazard from the laser source to this distance. Radiation is above a Maximum Permissible Exposure (MPE) as determined through AS 4970 tables, where MPE depends on wavelength.

- *Sensitive Zone Exposure Distance:*
  The beam is bright enough to cause temporary vision impairment from the source to this distance.

- *Critical Zone Exposure Distance:*
  The beam is enough to cause a distraction interfering with critical task performance from the source to this distance.

For each distance, it is important to determine the distance directly along the beam as well as the ground covered (horizontal distance) and the altitude (vertical distance).

Throughout calculations, the Maximum Permissible Exposure (MPE) plays a critical role. The easiest way to find the MPE is to use AS 4970 tables. They provide a simple conservative method. FAA Order 7400.2E also includes similar tables.

The site, operational volume and hazard distances have to be illustrated on Visual Flight Rules (VFR) maps. By overlaying the projected area of the operational volume and hazard distances on a VFR map, a “picture” of the potentially affected volume can be obtained. Besides VFR maps, electronic means are already available for plotting risk areas and zones.

4.2 Second Step - Identification of Local Airports and Hazard Zones

Depending upon the laser site, hazard distances will define hazard zones around affected airports. Using VFR maps from all airports near the proposed laser site, critical and sensitive zones can be identified around each airport. Airport zones beyond the greatest identified distance do not need to be considered

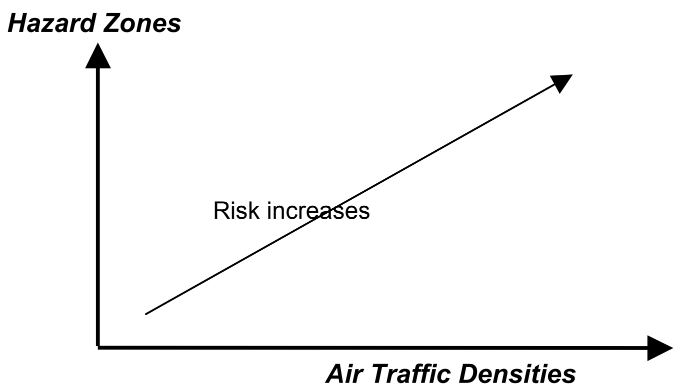
4.3 Third Step - Analysis of Aircraft Patterns and Densities

If an airport hazard zone is impacted by the laser operation or an NOHD will penetrate navigable airspace, air traffic patterns and densities should be determined to evaluate the magnitude of potential impact

4.4 Fourth Step - Relative Risk of Airspace

This step would identify defined volumes of airspace that have higher or lower risk levels as a result of hazard zones, patterns and densities. This information can be useful in determining control techniques and methodologies.

Airport hazard zones have to be evaluated in the light of air traffic patterns. It is necessary to identify the relative risk levels of the airspace based on the evaluation. This could be illustrated on a basic graph:

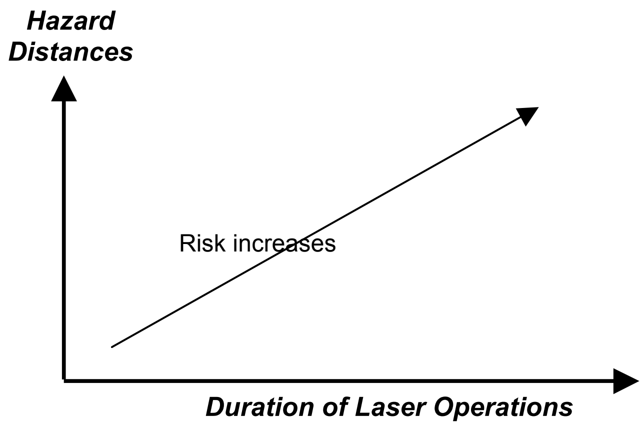


4.5 Fifth Step - Duration of Laser Operations

The duration of laser operations is to be defined through information provided by the proponent as part of his notice of proposal to conduct outdoor laser operations.

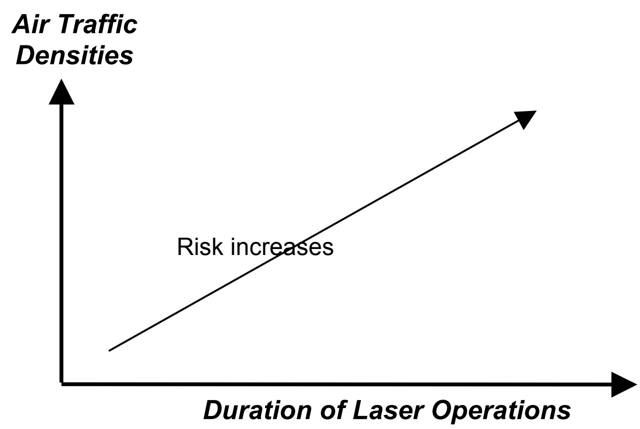
4.6 Sixth Step - Relative Risk of the Laser Operations

This step balances hazards presented by the laser with the time, duration and conditions of the operations as presented in the following diagram:



4.7 Seventh Step - Relative Risk of Laser Operations versus Airspace

Its objective is to provide a qualitative risk level for the proposed laser operations at the proposed site. When combined with hazard distance to the at-risk air space/hazard zones and the operational requirements and limitations of the laser operations, these qualitative risk level assists in defining the types and levels of protection required. A combined diagram can be obtained from the previous figures:



5. NAVIGABLE AIRSPACE CONTROL MEASURES

As the risk increases as shown in the previous diagrams, stronger mitigation measures will have to be defined and implemented to ensure tolerable levels of risk.

Normally, navigable airspace control measures will be required within the affected airspace areas, while airspace beyond the greatest identified hazard distance need not to be considered. This means that, assuming air traffic may be present during the period of laser activity, control measures must be utilised within affected flight zones to ensure protection against hazardous beams. Conversely, if there will be no traffic in the area at the time of the laser activity, mitigation measures are not necessary.

5.1 SAE/FAA Approach

SAE AS4979 designates airspace volumes as normal flight zones, sensitive flight zones, critical flight zones and laser-free flight zones. FAA has also adopted this pattern. Each type of zone is associated with acceptable laser beam irradiance levels.

- *Sensitive Flight Zone*:
  This zone encompasses the area on the ground or volume of airspace where exposure to intense visible beams would interfere with critical tasks, but not jeopardise safety.

- *Critical Flight Zone:*
  Covering the area on the ground or volume of airspace where interference with critical visual tasks would jeopardise safety.

- *Laser Free Flight Zone:*
  Visual interference by a laser beam would pose significant safety problems. There, visible laser beams should not interfere with a pilot's vision.

Normal flight zones comprise all airspace that may contain an aircraft and is not included in the other three zones.

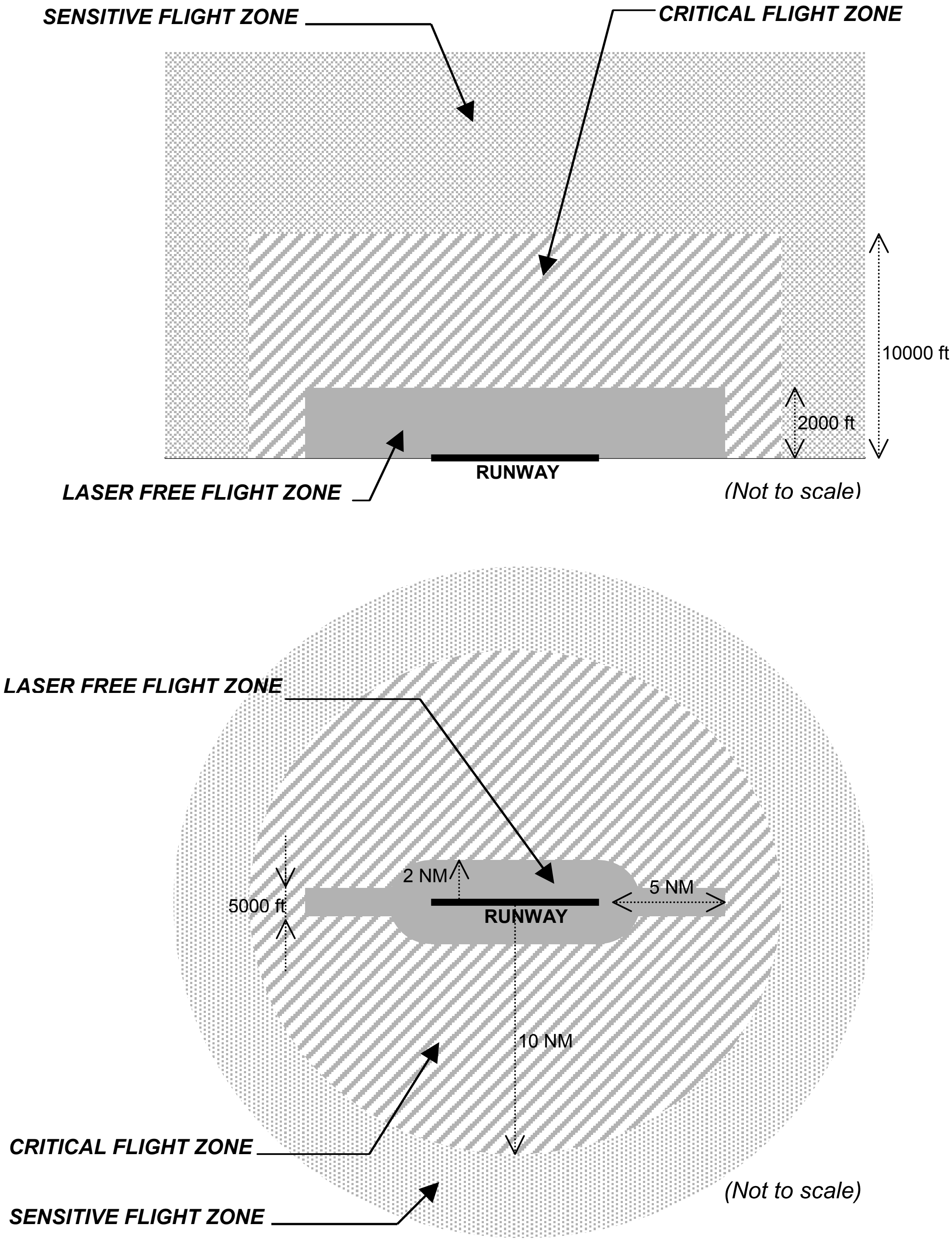
In practical terms, these definitions provide three successive layers to be associated with different levels of protection. Particularly, laser-free zones would cover the closest area around airport runways. Figures presented in the next page illustrate these zones defined around each runway affected by outdoor laser operations at a particular airport.

SAE AS4970 and FAA 7400.2E propose the following basic dimensions for these zones:

- *Critical Flight Zone:*
  Airspace within a 10 NM radius of the airport reference point, up to and including 10000 ft AGL.

- *Laser Free Flight Zone:*
  Airspace in the immediate proximity of the airport, up to and including 2000 ft AGL, extending 2 NM in all directions measured from the runway centreline. Additionally, the zone includes a 3 NM extension, 2500 ft each side of the extended runway centreline, up to 2000 ft AGL of each useable runway surface.

- <u>*Sensitive Flight Zone:*</u>
  Outside the critical zone, the dimensions of a sensitive area would be determined by airport operations depending upon several local factors.



(Figure – Zones Proposed by SAE AS 4970 and FAA 7400.2E)

The levels of protection associated with these layers are based on three basic principles:

- Normally, outdoor laser operations should not affect laser-free flight zones at all. However, this does not totally preclude the use of lasers in the zone, provided that appropriate risk mitigation is taken into account to ensure aviation safety.

- Lasers with beam irradiances less than the MPE, but exceeding the sensitive level or critical level may be operated in the sensitive zone or critical flight zones, respectively, if adequate control means are used to prevent aircraft from entering the beam path. Normally, safety observers will be deployed to provide such prevention, especially during short-duration laser operations. Electronic means (to be accepted by the regulatory agency) may provide alternative means in some specific situations.

- Any affected air traffic control facility should be able to directly communicate with the authorised laser operator to stop the laser beam if aviation safety is compromised.

5.2.1 Control Measures:

FAA has already identified physical, procedural, and automated control means to ensure that aircraft operations will not be exposed to levels of illumination greater than the maximum irradiance level considered as acceptable in each affected flight zone.

The list of possible control measures may include:

a) Physical beam stops at the system location or at a distance used to prevent laser light from being directed into protected volumes of airspace;

b) Adjusting the beam divergence and output power emitted through the system aperture to meet appropriate irradiance distance;

c) Directing beams in a specific area. Directions should be specified by giving bearing in the azimuth scale 0^{o}-360^{o} and elevation in degrees ranging from 0^{o}-90^{o}, where 0^{o} is horizontal and 90^{o} is vertical, bearings should be given in both true and magnetic north;

d) Manual operation of a shutter or beam termination system can be used in conjunction with airspace observers. Observers should be able to see the full airspace area surrounding the beam’s path to a distance appropriate to the affected airspace;

e) Scanning safeguards that are designed to automatically shift the direction of the laser emission can be used. However, scanning safeguards should be formally accepted by the regulatory agencies;

f) Automated systems designed for use to detect aircraft and automatically terminate, redirect the beam or shudder the system, should be accepted by the regulatory agencies before the device may be accepted as a control measure which satisfies as an equivalent level of safety.

In addition, SAE AS4970 provides some examples of preventive and control measures that have been successfully used to protect airspace. The standard presents a varied range of options (Observers, Camera observers, Radar observers, and other technologies)

Criteria are also proposed to select a reasonable control technique depending on the applicable hazard ranges and obscuration conditions.

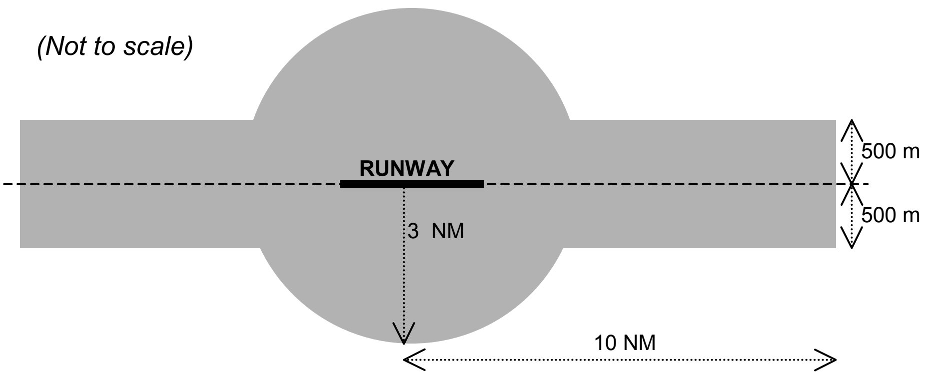
Additional information is given on the role of Observers. The standard also proposes a possible list of responsibilities for observers, operators and other involved people.

SAE highlights that the choice of preventive techniques should be based on the level of hazard presented by laser operations. The Laser Safety Analysis Methodology (see previous sections) may provide information to be used in the determination. In order to accept possible control measures, the regulatory agency should:

- Identify all methods, procedures, systems, etc, which can be used to avoid laser illumination of aircraft.
- Document and maintain on file all analyses and approvals
- Re-evaluate the analysis and preventive techniques whenever the system is modified or after a certain period.

5.3 UK DAP Approach

Following a more simple pattern, the UK DAP has proposed the following zones and associated control measures around airport runways, as illustrated by the following figure:



(Figure – Zones Proposed by UK DAP Guidelines)

For events that take place within 500 m either side of the extended runway centreline within 10 miles of an aerodrome, the following guidelines apply:

a) Lasers should have a maximum peak radiant power of 20 Watts.

b) Beams should be below the horizontal or a physical barrier such as building or a land feature should be in place to prevent light escaping along the centre-line.

c) If this is impractical, the event organisers should arrange a telephone or radio contact through which the light display can be extinguished immediately on request from an aircraft or the affected aerodrome.

d) If this is not possible, then the light display may represent a threat to flight safety and should not proceed.

For events which take place within 3 miles of an aerodrome but not on the extended runway centre-line, the above guidelines would apply but with the addition that any light should not stray towards the aerodrome or the extended runway centre-line.

Elsewhere, if a light display is particularly powerful or takes place under a known air traffic route, the organisers should notify the regulatory body of that activity.

It should be noted that the UK approach has been kept deliberately uncomplicated. It focus attention on protecting aircraft during landing and take-off and in the visual circuit, since this is when any temporary loss of vision by a pilot may eventually cause the worst hazardous situations.

5.3 NOTAM

Issuance of NOTAM is essential to alert pilots of outdoor laser operations. The NOTAM should emphasise the potential hazardous effects and other related phenomena that may be encountered by laser emissions.

Clearly, this requires laser operators to notify the appropriate agency well in advance of their proposed laser activity.

6. PILOT PROCEDURES:

At present, a pilot's best defence against laser flashes is knowing where and how to avoid them. The locations, dates, duration and eye-safe distances for approved displays should be published in any case through aeronautical information services.

Transport Canada has developed and published as an aeronautical information circular, specific information and guidelines for flight crews encountering laser illuminations. SAE AS4970 also deals with this particular matter. Actually, both documents contain similar information.

Directed bright light sources, particularly laser beams, projected near airports or into any airspace can cause two flight safety concerns:

- The primary concern involves non-injurious, bright levels of directed light unexpectedly entering the cockpit. Depending on the brightness level, the light could startle the pilot(s); could cause glare, making it difficult to see out the windshield; or could even create temporary vision impairment (flashblindness and/or afterimage). The illumination and glare may be short—one or a few bright flashes—but the startle and afterimage effects could persist for many seconds or even minutes.
- A secondary concern is if a laser beam is so powerful that it causes temporary or permanent eye injury to anyone (pilot, crewmembers, passengers) viewing it. Fortunately, this is only a remote possibility because the laser power required to cause eye injury to a pilot in flight greatly exceeds that of lasers in common use today.

Therefore, the most likely in-flight safety hazard is that of a bright non-injurious flash causing disruption in the cockpit workflow. Such effects pose significant flight safety hazards when the cockpit workload increases below 10000 ft. above ground level (AGL), in critical phases of flight (approach and landing), dense traffic areas (terminal environment and en-route areas), and in proximity to airports. This safety hazard is applicable to both single or dual aircraft cockpit operations.

Even laser pointers can cause adverse effects that could cause pilots to be distracted from their immediate tasks. Exposures to pilots from persons using laser pointers have been reported, particularly against law enforcement helicopters.

6.1 Procedures

Preventative measures and incident procedures can be followed to either prevent potential illuminations or minimise cockpit disruption if one occurs. For simplicity, the following procedures, proposed by Transport Canada and SAE, refer to laser illumination incidents; however, similar procedures should be applied regardless of the source, either laser or any other directed bright light such as a searchlight.

Preventive procedures:

During aircraft operations into navigable airspace where laser or other directed bright light activities are anticipated, flight crews should:

- Consult NOTAM for temporary laser activity. The NOTAM should include the location and time of the laser operations.
- Avoid known permanent laser displays (e.g., Disney World). In the U.S., these sites are published in the Airport/Facility Directory. Not many permanent sites exist for the time being in other countries.
- Turn on additional exterior lights to aid ground laser safety observers in locating aircraft so they are able to respond by turning off the laser beam.
- Turn on thunderstorm lights to minimise cockpit illumination effects.
- Engage the autopilot.
- Keep one pilot on instruments to minimise the effects of a possible illumination while in the area of expected laser activity.
- If flying a helicopter engaged in surveillance or medical evacuation, consider using notch filter eye spectacles that protect against 514- and 532-nanometer laser wavelengths.

Laser incident procedures:

If a laser beam illuminates a pilot in flight, the pilot should:

- Immediately look away from the laser source or try to shield the eyes with a hand or a hand-held object to avoid, if possible, looking directly into the laser beam.
- Immediately alert the other pilots and advise them of the illumination and its effect on your vision.
- If vision is impaired, immediately transfer control of the aircraft to the other pilot. If both pilots have been illuminated, engage the autopilot.
- Be very cautious of spatial disorientation effects (the "leans"). After regaining vision, check cockpit instruments for proper flight status.
- Resist the urge to rub the eyes after a laser illumination as this action may cause further eye irritation or damage.
- Contact air traffic control (ATC) and advise of a "laser illumination." Use appropriate terminology for all laser incident/accident reports. If the situation dictates, declare an emergency.
- When time permits, provide ATC with an incident report, which would include the location, direction, beam colour, length of exposure (flash or intentional tracking), and effect on the crew.

Medical follow-up procedures:

After a laser occurrence, any crewmember or passenger that has been subjected to a significant illumination causing persistent symptoms such as pain, visual abnormalities (e.g., flashblindness and/or afterimage) should seek immediate medical attention. In addition, aviation medical authorities should be contacted at the earliest opportunity. They may provide assistance in locating the nearest ophthalmologist or medical facility with experience in evaluating laser injuries. An eye damaged by a laser beam starts to repair itself immediately.

Therefore, it is strongly recommended that an ophthalmologist familiar with laser injury examination requirements evaluate the crewmember or passenger within five hours of the exposure to determine the nature of the injury and if it needs further follow-up action.

Because diagnosis can be difficult, especially for medical personnel who rarely, if ever, see laser eye injuries, it should not be automatically assumed that a particular symptom, abnormality or injury was caused by a given laser exposure.

7. REPORTING LASER SAFETY OCCURRENCES

As widely known, safety occurrences reporting is essential to detect safety problems and identify ways to mitigate existing risks. Normally, the number of reported incidents would determine whether this would be classified as a key risk area, with mitigation action necessary.

SAE AS 4970 proposes a form to be used by pilots when reporting laser occurrences. It is a three-page questionnaire intended to collect specific and detailed information about the laser occurrence.

8. USEFUL REFERENCES

- SAE Aerospace Standard AS4970*, 'Human Factors Considerations for Outdoor Laser Operations in the Navigable Airspace'*, December 1999 (Published document).

- FAA 7400.2D Order, Chapter *34 'Outdoor Laser/High Intensity Light Demonstrations'* (Draft document as available in September 2000).

- FAA 7400.2E Order, Chapter 29 *'Outdoor Laser Operations'* (Draft document as available in September 2000).

- FAA Advisory Circular *'Outdoor Laser Operations'* (Draft document as available in September 2000).

- UK Directorate of Airspace Policy, *'Safeguarding Co-ordination – Guidelines for Outdoor Use of Lasers, Searchlights and Fireworks (Second Issue)'*, 7 July 1998.

- Transport Canada, Notice of Proposed Amendment NPA 99-145 to CAR 601, Division II, *'Aircraft Operating Restrictions to Aviation Safety'*, 26 August 1999 (available on Transport Canada web-site).

- Transport Canada, Aviation Safety Vortex 1/2000*, 'Exposure to Laser and Other Directed Bright Light Sources – Pilot Procedures'*, 27 April 2000 (Available on Transport Canada web-site).

- US Food and Drug Administration – Center for Devices and Radiological Health, HHS Publication FDA 86-8261, *'Laser Light Show Safety-Who's Responsibility?'* (Available on the FDA CDRH web site).

- NASA Aviation Safety Reporting System, ASRS Directline, Issue 7, September 1995, *'More than Meets the Eye – Problems with Laser Light Shows'* by Marcia Patten (Available on the NASA ASRS web-site).

- American National Standards Institute (ANSI), Z136 series of standards.

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Appendix A

List of Specific Terms and Useful Definitions

Aircraft	Device(s) that are used or intended to be used for manned flight in the air (i.e., aircraft, helicopter, airships, hot air balloon, etc).
Airport	An area on land or water that is used or intended to be used for the landing and takeoff of aircraft and includes its buildings and facilities, if any.
Afterimage	The perception of light, dark, or coloured spots after exposure to a bright light that may be distracting or disruptive. Afterimages may persist for several minutes.
Critical Flight Zone (CFZ)	As defined by SAE and FAA, airspace within 10 nautical miles of the centreline of each runway and from the surface up to 10,000 feet above airport elevation (AGL). This may be adjusted to meet air traffic requirements.
Critical Zone Exposure Distance	As defined by SAE and FAA, the distance along the axis of the beam to the human eye beyond which the irradiance is not expected to exceed 5 $\mu W/cm^2$.
Continuous Wave Laser (CW Laser)	A laser that is operated in a continuous rather than a pulsed mode. According with SAE AS 4970, a laser operating with a continuous output for a period >0.25 s is regarded as a CW laser.
Flashblindness	A temporary vision impairment that interferes with the ability to detect or resolve a visual target following exposure to a bright light. This is similar to the effect produced by flashbulbs, and can occur at exposure levels below those that cause eye damage. This impairment is transitory, lasting seconds to minutes depending upon the laser's light exposure level and time, the visual task, the ambient lighting, and the brightness of the visual target.
Glare	A reduction or total loss of visibility, such as that produced by an intense light source, such as oncoming headlights, in the central field of vision. These visual effects last only as long as the light is actually present effecting the individual's field of vision. Visible laser light can produce glare and can interfere with vision even at low energies well below those that produce eye damage.

Irradiance	A measure of light energy spread across a given area, expressed in watts per square centimeter (W/cm^2). Irradiance levels at 50 nanowatts/cm^2, 5 microwatt/cm^2, and 100 microwatt/cm^2 refer to the equivalent visual effect from Argon (515 nm) or Nd:YAG (532 nm) lasers.
Laser	An acronym for light amplification by stimulated emission of radiation. A device that produces an intense, monochromatic, directional, coherent beam of light.
Laser Free Flight Zone	As defined by SAE and FAA, that volume of airspace within the "Critical Flight Zone" defined as airspace: a) From the surface up to 2,000 feet above airport elevation, extending 2 NM (12,152 feet) in all directions from the runway surface measured from the centreline. b) In addition, an extension out to 5 NM (30,380 feet) from the runway ends, and 2,500 feet each side of the extended runway centreline, at a slope of 40:1, and up to 2,000 feet above the airport elevation of each usable runway surface. c) Parallel runways are measured from the runway centreline toward the outermost edges, plus that area between the runway centrelines.
Laser Operator	A knowledgeable person present during laser operations who is responsible for ensuring compliance with applicable safety standards.
Maximum Permissible Exposure (MPE)	The level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin. The MPE for visible CW lasers is 2.6 milliwatts (mW)/cm^2. Pulsed lasers require correction factors based on pulse duration and repetition rate to obtain an equivalent exposure.
Nominal Ocular Hazard Distance (NOHD)	The distance along the axis of the unobstructed beam from the laser to the human eye beyond which the irradiance is not expected to exceed the MPE. For visible CW lasers, the MPE is 2.6 milliwatts/cm^2.
Normal Flight Zones	All airspace not defined by the critical, or sensitive zones.

Observer (or Laser Safety Observer)	One who is responsible for monitoring the safe operation of laser demonstrations, and can effect termination of the laser emission in the event an unsafe condition is imminent. Observers must have sufficient training to be able to recognise unsafe conditions. Laser safety observers for outdoor laser displays may also be aircraft observers (spotters), and should have specific training to identify aircraft at a distance.
Sensitive Flight Zone	As defined by SAE and FAA, all airspace outside the critical flight zone(s) that authorities have identified as zones that need protection due to anticipated high visual cockpit workload. This may or may not be contiguous or concentric with the critical airspace.
Sensitive Zone Exposure Distance	As defined by SAE and FAA, the distance along the axis of the unobstructed beam from the laser to the human eye beyond which the irradiance is not expected to exceed 100 $\mu W/cm^2$.