LASER BIRD REPELLENTS – A PAIN IN THE EYE?

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Abstract

Most non-military laser use is indoors. Over the years, this has resulted in the development of procedures for safe use of even the most powerful lasers. Sufficient means are available for shielding laser beams and control of access to the laser area. Thus, these lasers can be used with minimal risk.

In military applications, most use of lasers is outdoors and exposure to the laser beam cannot physically be prevented. Often, low power modes are available for training purposes. For the rest, powerful lasers are dealt with as if they are weapons. The risk of exposure is reduced by operating procedures, training and discipline.

Non-military outdoor use of high powered lasers, i.e. of Classes 3B and 4, mostly occurred in a relatively professional and controlled setting, e.g. in atmospheric research or at artistic laser displays. However, over the years, access to powerful laser pointers has become quite easy for the general public. The purchase and use of even the highest class of lasers may be perfectly legal. In the Netherlands, for instance, it is not allowed for retailers to sell Class 3R, 3B and 4 lasers to civilians, but possession and use thereof is legal. Thus, the use of powerful lasers now is more widespread and people that have no training are using them in an uncontrolled environment, sometimes with the intend to harm or hamper.

A new risk is developing; powerful lasers for repelling birds or other animals away from airports or agricultural fields. In some cases, these lasers will also be used by professionals, in a setting where safety measures are in place and the public will not easily be exposed, such as airports and off-shore helicopter platforms. In other cases, these bird repelling lasers will be used by poorly or not trained persons, not restricted by operating procedures, and at places that are easy accessible for the public. The associated risks are substantially greater than those for high powered laser pointers, as the bird repelling lasers do not only have high power, they have low divergence as well. The effect is that these lasers have hazard distances of kilometres, rather than tens or hundreds of metres, as will be explained in this paper.

Introduction

In the last decades, lasers have been used for dispersing birds. Initial experiments were conducted by aiming relatively low power red laser beams (Figure 1) directly into the flock of birds. These experiments were conducted before sunrise and after sunset, as the low powered lasers were not effective under daylight conditions [1].

Figure 1 Laser rifle as used in ref. [1]. The Desman© laser (model FL R 005) holds a 632.8 nm helium-neon laser with an output of 5 mW. Beam diameter at the exit is 12 mm and divergence is 0.3 mrad. It is labelled as Class 3B. (source: www.desman.fr)

While the early laser bird repellents have a relatively low output power, modern laser bird repellents are much more powerful, making them solid Class 3B or even Class 4 devices. Instead of red light, the use of green 532 nm lasers is now preferred. The sensitivity of the human eye is 15-20 higher for the green light, which may be the case for birds as well. In any case, green foliage will absorb a large fraction of the red light, whereas green light is reflected and will therefore be brighter.

Whereas in the past the laser beam was aimed in the flock or in the eyes of the birds, the newest technique is to move a laser spot over the surface (fields, roofs) towards the birds. The manufacturers claim that birds perceive the approaching spot as an approaching physical object, making them fly away.

In order to be effective during daytime conditions, the spot has to be sufficiently bright in order to be noticed by the birds. An estimate of the order of magnitude for the intensity (irradiance) that has to be realised at the location of the spot can easily be made:

- The irradiance by the sun in mid-latitude regions is in the order of 100 mW/cm^2,
- The visible faction accounts for roughly 40%. It is here assumed that this is true for birds as well,
- In order to create a clearly visible spot at sun lit green foliage, an irradiance is required that is significant when compared to the solar irradiance, here it is assumed it has to be at least 20-25%,
- This would result in an irradiance by the laser of 8-10 mW/cm².

Note that this is way above the Maximum Permissible Exposure (MPE) of 2.55 mW/cm² (or 25.5 W/m²), for ≤0.25 s duration exposure. Also, note that this is the desired irradiance at a location near the birds. Due to the vigilance of birds, this is at a large distance from the laser operator (0.3-1.5 km). This high irradiance cannot be realised by commercially available laser pointers. The solution to create a spot having high irradiance, over a wide range of distances, is to have a device outputting a relatively wide beam with minimal divergence. This can be realised by using a beam expander, see Figure 2.

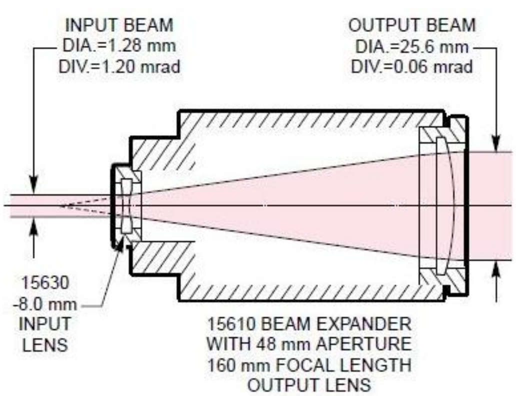

Figure 2 Example of a 20x beam expander (source: www.azooptics.com).

The effect of using the beam expander as shown in Figure 2 in combination with a typical 200 mW laser is given in Table 1. It can be concluded that when operating at a distance of 500 m, a beam expander is conditional for creating a spot of light that will be visible, even under daylight conditions.

Table 1 Effect of a 20x beam expander on the spot size *d* and irradiation *E* at a distance of 200 m, given for a 1.28 mm, 1.20 mrad, 200 mW laser beam.

No expander	Including expander
d = 601 mm *E* = 0.07 mW/cm^2	*d* = 55.6 mm *E* = 8.1 mW/cm^2

If it comes to laser safety, the effect of using a beam expander is explained in Figure 3. In case of the pointer and expander as referred to in Figure 2 and Table 1, the irradiance starts at a value greater than 100 mW/cm², to drop below the MPE within 100 m. By adding a 20x expander, the irradiance within the first 20 m is reduced. However, from that point onwards, the irradiance is significantly higher and it takes more than 1,000 m to drop below the MPE.

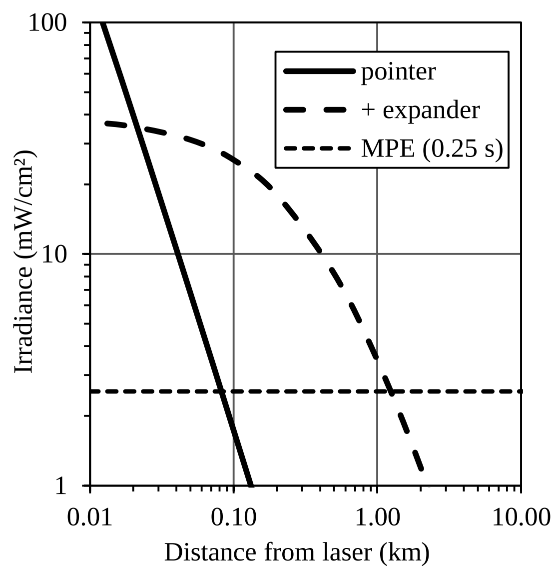

Figure 3 Irradiance as function of distance for the two configurations in Table 1. For the pointer, the irradiance drops below the MPE within 100 m. For the expanded beam, it takes more than 1,000 m.

Therefore, laser devices that have been developed to disperse birds from great distance, will have a Nominal Ocular Hazard Distance that is far greater than that of high powered laser pointers. This makes it important that these lasers are provided with detailed technical and safety information, clear instructions and, of course, by the correct laser Class labelling.

Class verification for the Aerolaser Handheld

Bird Control Group in the Netherlands is a manufacturer of laser bird repellents. Three copies of the Aerolaser Handheld (Figure 4) were acquired for use by the Royal Netherlands Air Force. The devices were labelled Class 2M, <50 mW output power. The users were impressed by the intensity of the beam, which was higher than what could be expected on the basis of the laser class. The Royal Netherlands Navy (responsible for laser safety evaluation and training of Laser Safety Officers within the Dutch Armed Forces) was asked to verify the class of this laser, and to assess the hazard distances.

Figure 4 The Aerolaser Handheld. Manufacturer: Bird Control Group, Delft, the Netherlands.

Method

In order to assess laser class and to calculate hazard distances, (1) the laser wavelength, (2) power, (3) accessible emission (see ref. [2]) and (4) beam parameters had to be measured.

Laser wavelength was measured using an Ocean Optics HR4000 spectrometer.

Laser power was measured using the Ophir PD300-3W, which is a photodiode sensor that has a 10x10mm aperture. The sensor was used in combination with a Pulsar 4 computer interface. A Plano-convex lens (15 cm diameter, f = 200 cm) was used to reduce the beam width such that it was completely projected onto the sensor surface. The sensor itself was placed out of focus, at 150 cm from the lens. This was done as a precaution, as placing the sensor in the focal plane can result in damage by the highly-concentrated beam. The transmission coefficient for this lens is 0.91 at the wavelength of 532 nm, which factor was used for correcting the readout of the sensor.

Laser beam parameters were measured by camera based beam profiling, to obtain 2D and 3D views of the beam profile and to measure beam dimensions. A set-up was used in which the beam is projected onto a trans missive diffuser plate, similar to a method described in ref. [3]. The intensity distribution of the spot was measured by a Spiricon SP620U Beam Profiling Camera, which was placed behind the plate. The camera is connected to a laptop computer with Spiricon Beamgage software for data acquisition and analysis.

The Spiricon software was programmed to obtain the dimensions of the ellipse that holds 63% of the energy, conform ref. [2]. Before measurement, the set-up was zeroed to compensate for background signal using the UltraCal™ algorithm that is part of the software.

The method that is chosen for determining the divergence, is to assess the beam profile at multiple distances from the laser. The divergence is then calculated on the basis of the increase in diameter as function of distance. Two surface coated mirrors were used to fold the beam in such a way that an optical path length of up to 140 metres could be realised. The mirrors used are extremely flat (radius > 70 km).

Results

The laser wavelength was 532 nm, no other wavelengths were detected.

It was found that the laser power was highly fluctuating (Figure 5). This was observed for all three devices.

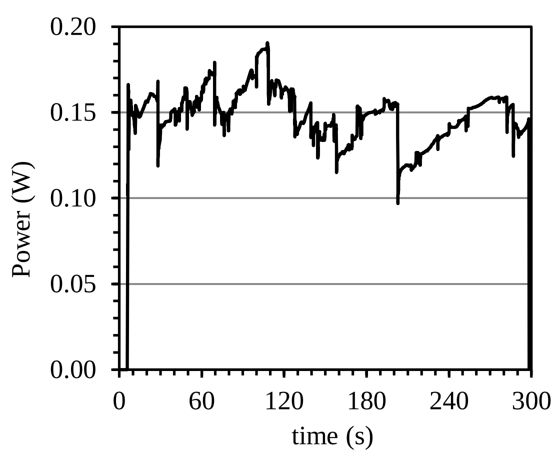

Figure 5 Power as function of time for one of the three devices tested.

The maximum value measured was 191 mW, which is significantly higher than the specified output, which is <50 mW. For the NOHD calculation, the more conservative value of 200 mW was used.

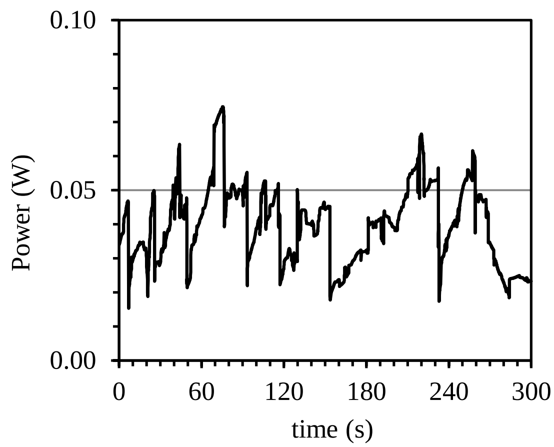

Figure 6 Accessible Emission for Condition 3 (ref [2], 7 mm aperture) for one of the three devices.

Laser classification is based on the accessible emission. For 532 nm laser light, the apertures for Conditions 1 and 3 in the simplified classification procedure are 25 mm, respectively 7 mm (see ref [2]). The result for the 7-mm aperture is given in Figure 6. The highest value measured for any of the three devices equals 84 mW, which value was used in assessing the laser class.

When examining the beam profile, it was observed that the profile and dimensions were highly unstable. Mode hopping was clearly visible. Again, this was the case for all three lasers. For part of the time, the beam profile was somewhat Gaussian shaped. More frequently, the profile was rather chaotic: Sometimes, the TEM_{10} seemed dominant, at other occasions TEM_{01} was more dominant. This has implications for the hazard assessment: The laser beam will be considered to be non-Gaussian which has an effect on the NOHD calculations.

The increase of beam width and beam height as function of distance *l* is given in Figure 7. Linear regression by Excel for the data sets obtained at 30 m, 70 m and 140 m resulted in:

- Beam width (mm) = $0.071 \cdot l + 16.9$ ($R^2 = 0.999$),
- Beam height (mm) = $0.053 \cdot l + 14.186$ ($R^2 = 0.999$).

The results show that the beam is slightly elliptical. In the NOHD calculation, the beam is treated as being circular. A circle having a cross sectional area equal to that of an ellipse can be defined by $d_{63} = \sqrt{x_{63} \cdot y_{63}}$, in which x_{63} and y_{63} represent the beam width and height. In order to account for unknown factors such as product variability, temperature dependence and beam instability, conservative values are used for the NOHD calculation: d_{63} = 15 mm at a waist located at 15 m from the laser, and divergence equals 0.05 mrad.

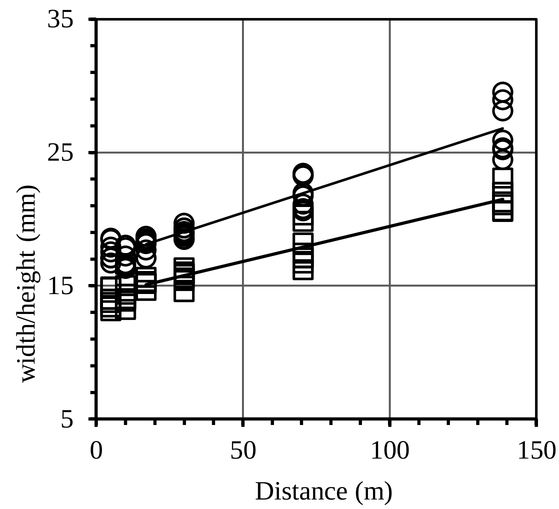

Figure 7 Development of beam width (upper line) and beam height (lower line) as function of distance *l*. As a result of mode hopping, the dimensions are not stable. Results for one laser device are shown here, the other devices produced similar results.

Verification of the Laser Class

The classification rules as given in the sections of §4.3 of ref. [2] are considered here individually:

4.3.a) this is a single wavelength product and shall be classified accordingly.

4.3.b) the presence of radiation of multiple wavelengths does not need to be considered.

4.3.c) this is not an extended source, as can be concluded from what is stated at page 42 of ref [2]: "In the case where the divergence of the laser beam is less than 1.5 mrad, then the angular subtense of the apparent source α is smaller than α_{min} and the determination of the accessible emission may be performed under the conditions specified in 5.4.2."

4.3.d) this is a non-uniform source, the wavelength is within 400-1400nm, yet the AEL does not depend on C_6 as C_6 =1. So, there are no implication of this section.

4.3.e) The time base shall be 100 s for Class 1 and Class 3B evaluation, and 0.25 s for Class 2, 2M and 3R evaluation.

4.3.f) This is a CW laser, so this section is not relevant.

On the basis of this consideration, the default (simplified) evaluation for the laser class can be used (§5.4.2 of ref. [2]). The measured Condition 3 Accessible Emission value of 84mW then has to be compared against Accessible Emission Limit (AEL) values (see pages 34 and onwards in ref. [2]):

- Class 1: 0.39 mW
- Class 2: 0.99 mW
- Class 3R: 5.0 mW
- Class 3B: 500 mW

It will be clear that the Condition 3 AE value of 84mW (Figure 6) for the Aerolaser Handheld exceeds the limits for all classes except that for Class 3B. Therefore, the Aerolaser Handheld is Class 3B.

NOHD calculations

Ref. [2] does not describe, nor prescribe a method for calculating hazard distances. In ref. [4] however, the following equations are given for calculation of the (e)NOHD in case of CW lasers:

$$NOHD = \frac{1}{\varphi}\sqrt{\frac{4 \cdot k \cdot P}{\pi \cdot E_{\mathrm{MPE}}}} - \frac{a}{\varphi} + w$$

and

$$eNOHD = \frac{1}{\varphi}\sqrt{\frac{4 \cdot k \cdot \tau \cdot G \cdot P}{\pi \cdot E_{\mathrm{MPE}}}} - \frac{a}{\varphi} + w$$

For the Aerolaser Handheld, the values for the parameters in the equations are:

$\varphi = 0.05 \cdot 10^{-3}$ rad divergence angle

$k = 2.5$ as the beam is non-Gaussian

$P = 0.2$ W total power of the laser

$a = 0.015$ m diameter of the beam at waist

$w = 15$ m position of waist

$\tau = 0.90$ transmission for binocular (see page 27 of ref. [5])

$G = 49$ dimensionless gain factor for the binocular. In this case, a 7x50 binocular is assumed. The exit diameter then is 7.1 and the pupil is slightly overfilled. In that case $G = M^2 = 7^2 = 49$ (M is magnification, see page 23 of ref. [4]).

$E_{\mathrm{MPE}} = 25.46$ W/m^2 Maximum Permissible Exposure for the eye, see Table A.1 in ref. [2]. Note that this for an exposure duration of 0.25 s. The use of 0.25 s for the NOHD is discussed on page 28 of ref. [5]. In case of calculation of the skin hazard, the MPE is 2000 W/m^2 (see Table A.1 in ref. [2]).

This results in the following hazard distances:
- NOHD = 2.9 km
- eNOHD = 20.7 km
- NSHD = 72 m (>10 s exposure duration)
- NSHD = 0 m (≤5 s exposure duration)

Note the effect of the factor *k*. Only if this was a Gaussian beam, *k* = 1 can be used, in which case the distances would be respectively 1.7 km, 13 km and 0 m.

Discussion

Risks associated with the use of bird repelling lasers

It has been shown here that the bird repelling lasers that are effective at long range and during daytime, inherently pose a greater safety risk than equally strong commercial laser pointers. Awareness of this fact will by itself already contribute to mitigating the risks. In addition, an appeal is made here to endeavour that the use of these lasers is only allowed if the users are well trained, a risk assessment has been made and control measures are in place. For the use within the Armed Forces in the Netherlands, this is the case. The bird repelling lasers are used like any other high powered laser: not much different from how a weapon is used.

Misclassification

The Aerolaser Handheld was clearly not correctly classified. This is not to be ignored: The Class 2M label informs the user that the risk for the human unaided eye is minimal if the exposure duration is ≤0.25 s (by the aversion response). The laser should have been classified as Class 3B, which is two classes higher, and warns the user to avoid direct exposure. Strict application of the hazard distance calculation equations (ref. [4]) shows that risk of eye injury exists up to almost 3 km.

The limit value for Class 2M is exceeded by so much that the discrepancy with the results reported here cannot be explained by incidental off-spec functioning of the lasers, nor by a failing QA/QC process as a result of which the three lasers that were tested happen to be way off their design specification.

It was obvious that the discrepancy is the result of a misinterpretation of the classification standard. Therefore, the consultant responsible for the classification process was contacted. It soon became clear that the consultant dealt with the Aerolaser Handheld as if it is an extended source. Only after the exchange of multiple e-mails he could be convinced that his approach is incorrect.

Risk for animals

Over the years, and even in recent interviews, Bird Control Group has repeatedly stated that the use of this or similar lasers is safe, both for humans and birds. With respect to the risk for the human eye, the Class 3B qualification and the NOHD should be self-explanatory. With respect to claimed absence of hazard for birds: There is no research that can support this statement. The only publication on this matter is based on experiments with a single species (Cormorants), in which a very limited number of birds were exposed to a 5(!) mW HeNe laser [1]. This laser barely is Class 3B and from what is presented in this paper, it will be clear that any laser that is capable of disturbing birds under daylight conditions will output significantly more power.

The follow-up

By mid-2016, the manufacturer stated: "*Based on the evaluation of Mr. Mallant our consultant came to new insight on the classification of the Aerolaser Handheld. As the manufacturer, Aero Bird Control Solutions certifies the product as a laser class 3B device and takes appropriate measures towards existing users of the product.*"

Reference to Class 2M has been removed from the company website, which unfortunately has resulted in a situation in which at present totally no information on laser class can be found.

Meanwhile, it has become clear that other products offered by Bird Control Group have been under classified as well. For the Agrilaser Lite, this conclusion is based on measurements by the author, the Agrilaser Handheld has been sold as 2M whereas an independent laboratory concluded 3B, and in a Bird Control Group brochure, the 1,400 mW Aerolaser Groundflex MAX is listed as Class 3R, which is virtually impossible. In addition, under classification has been reported by persons active in the field of wildlife hazard management and bird strike risk mitigation [6].

In the beginning of 2017, several suppliers of the Bird Control Group products still have the incorrect laser class mentioned on their websites. Communication with persons active in the field of wildlife hazard management and bird strike risk mitigation has given reason to believe that the users of these products may not all have been informed [6], which for the author is a reason for concern.

Therefore, another appeal is made to the attendants of the 2017 International Laser Safety Conference, as well as to other peers in laser safety: If you are aware of the use of bird repelling lasers manufactured by Bird Control Group, inform the users that their laser may be under classified.

Of course, from what is presented in this paper, it should be clear that any bird repelling laser, of whatever manufacturer, that is claimed to be effective during daylight conditions and that is classified below Class 3B, should be subject for suspicion.

Conclusion

Bird repelling lasers that have an extremely low divergence have hazard distances well beyond that what may be expected on the basis of their class or output power alone. As such, their use in open terrain is much more hazardous than that of the low-cost high powered laser pointers that are available via the internet.

The Aerolaser Handheld is no exception, the NOHD is nearly 3 km, for people using binoculars (e.g. plain spotters and birdwatchers) the nominal ocular hazard distance extends to about 20 km.

The Aerolaser Handheld as well as several other bird repelling lasers produced by Bird Control Group have been under classified, at least until mid-2016.

Irrespective of the manufacturer, a matter for concern should be the intended use of these powerful lasers: On one hand this will be at places where risk assessment, control procedures and training of personnel are in place, such as airports and oil rigs. On the other hand, however, and more alarming, it is anticipated that a significant number of these devices will be used by relatively untrained personnel, in an uncontrolled environment. This could create significant problems such as inflicted eye injury or accidents resulting from persons being hampered when executing critical tasks. Videos available at the internet indeed show that the risk associated with the use of these devices is not always appreciated, the laser devices are directed towards highways, aircraft and unsuspecting persons [7].

References

[1] Glahn, J.F, Ellis G., Fioranelli P. & Dorr B.S. (2000) Evaluation of moderate and low-powered lasers for dispersing double-crested cormorants from their night roosts, in Proceedings of The Ninth Wildlife Damage Management Conference, State College, PA, USA, 34-45.

[2] IEC 60825-1, Safety of laser products - Part 1: Equipment classification and requirements (IEC 60825-1:2014).

[3] ISO 11146-1 Lasers and laser-related equipment - Test methods for laser beam widths, divergence

angles and beam propagation ratios- Part 1: Stigmatic and simple astigmatic beams. Dated: 2005.

[4] IEC TR 60825-10 Safety of laser products - Part 10: Application guidelines and explanatory notes to IEC 60825-1. Dated: February 2002.

[5] IEC TR 60825-14 Safety of laser products - Part 14: A user's guide. Dated: February 2004.

[6] McKee, J, Avisure, (2017), Personal Communication.

[7] Guidelines on how to safely operate high powered lasers outdoors. https://youtu.be/kbvkOlgMVzo.

Meet the author

The author is a laser safety professional active for the Military Forces of the Netherlands. Involved in, or responsible for verification of laser parameters and laser classification, education of Laser Safety Officers, consultancy on laser safety and participation in NATO and IEC laser expert panels.