LA SER ILLUMINATIONS OF AIRCRAFT - A GROWING THREAT

Dangers to Pilot’s Vision from Handheld Lasers

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Overview

► Anatomy & Physiology of Vision
► Laser Hazard Factors
► Laser Effects & Eye Injuries
► Resources & Credits
Eye Anatomy

- **Cornea** - clear exterior
- **Pupil** - adjusts aperture for light
- **Lens** - focuses light on retina
- **Retina** - nerves responsible for vision
Eye Anatomy

Normal

Cornea
Pupil
Lens
Retina

Image focused on the retina
Eye Anatomy

► Retina
  ▪ Nerves / vessels light receptors
  ▪ Cones - in Macula → color/detailed sight
    ▷ Blue (475 nm)  Green (510 nm)  Red (650 nm)
  ▪ Rods - Peripheral → motion/night vision

► Optic Nerve
  ▪ Responsible for “blind spot”
  ▪ Transmits signals from retina to brain
Visible Light Spectrum

Blue

Green

Yellow

Red
Retina
Physiology

- Brain perceives visible light
- Eye exposed to IR - visible - UV
- Eye 35x more sensitive (green vs. red)
- Retina damaged by IR energy / heat
Light Wavelength

- **UV - 280 - 400 nm**
  - Absorbed - Iris, Lens, Cornea, A/V humor

- **Visible - 400 - 760 nm**
  - Impacts retina

- **Near IR - 760 - 1400 nm**
  - Absorbed by retina

- **Lasers produce full spectrum**
- Vitreous humor
- Iris
- Aqueous humor
- Lens

300 – 400 nm
Absorbed by: Aqueous humor, Iris, Lens, and Vitreous humor

400 – 1400 nm
Absorbed by Retina

< 300 nm & > 1400 nm
Absorbed by Cornea
Sensitivity by Wavelength

- Perceived brightness - Equal Power
  - Maximum near 550 nm (Green - Yellow)
  - Red (630-670 nm) 8 - 35 times less bright
  - Blue similar to Green
Physiology

- Dark conditions
  - Pupils dilate
  - Use rods for low ambient light
  - Use non-macular vision
  - Reduced visual acuity
  - Increased sensitivity to bright light
  - Red light enhances night adaptation
Night vs. Day Vision
Therapeutic Eye Uses of Lasers

- Diabetic Retinopathy
- Glaucoma
- LASIK
- Others
Diabetic Retinopathy
Laser Hazard Factors

► Laser Characteristics
► Laser Usage
► External Factors
► Protective Measures
Laser Characteristics

► Power Output
► Wavelength
  ▪ Color (Visible light)
  ▪ IR / UV components (Non-visible)
► Divergence
► Pulse vs. Continuous
<table>
<thead>
<tr>
<th>Class</th>
<th>Power</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt; 0.5 mW</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.5-1.0 mW</td>
<td></td>
</tr>
<tr>
<td>3a</td>
<td>1 - 5 mW</td>
<td></td>
</tr>
<tr>
<td>3b</td>
<td>5 - 500 mW</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>&gt; 500 mW</td>
<td></td>
</tr>
</tbody>
</table>
Laser Usage

► Direct vs. Indirect Illumination
► Daytime vs. Nighttime
► Distance to Aircraft
► Phase of Flight
Injury Potential

► Irradiance (energy / unit area)
  ▪ Pupil Size
  ▪ Focus
  ▪ Laser Factors
► Eye Focuses 100,000x Energy on Retina
► Blink & Turn
► Luminosity (Lumens/Watt)
External Factors

- Weather / Environmental
- Type of Aircraft / Operations
- Ambient Lighting
- Amplifying vs. Diminishing Devices
- Awareness of Hazard / Relative Risk
High Risk Environment

- Slow
- Close to Ground
- Predictable Flight Path
- Large Canopy / Windscreen Area
- Nighttime
- Visual Flight Rules
- Intentional Targeting
Protective Measures

► Crew Training and Reaction
  - ALPA Guidance
  - USAF / FAA Videos

► Filters not practical in civilian ops

► Glare shields / Light blockers

► Public Education

► Legislation and Enforcement
Terms

▶ Nominal Ocular Hazard Distance
  ▪ Maximum possible distance for permanent eye damage (< MPE)
  ▪ Assumes blink = 0.25 sec
  ▪ Assumes 7 mm dilated pupil
  ▪ Assumes direct continuous exposure

▶ Maximum Permissible Exposure
  ▪ 50% probability, worst case scenario
Laser Effects & Eye Injuries
Laser Effects & Eye Injuries

► Effects
  - Temporary, Self-Resolving
  - Usually no evaluation or treatment
  - May Compromise Safety

► Eye Injuries
  - Temporary, may require treatment
  - Permanent, little clinical significance
  - Permanent, significant disability
Temporary Laser Effects on Pilots

► Distraction
  - Diverted attention

► Glare
  - Dazzling sensation, discomfort interferes with optimal vision

► Afterimage
  - Transient Image in visual field

► Flash blindness - visual loss after light
No Laser Exposure
Distraction - 0.5 µW / cm²
Glare - 5.0 µW / cm²
Flash Blindness - 50 µW / cm²
Risks of Laser Effects

► Aviation Safety
  - Highest risk @ critical phases of flight
  - Unable to complete landing safely
  - Inability to see instruments clearly
  - Difficulty Taxiing

► Personal Health
  - Primarily psychological
Temporary Laser Eye Injuries

- Pain
- Burning
- Photophobia (light sensitivity)
- Slowed Pupillary Response
- Accommodative Spasm
- Psychological - Fear
  - Vision, Safety, Income, Career
Permanent Laser Eye Injuries

► Retinal Damage
  - Burns
  - Hemorrhage
  - Hole

► Corneal Clouding

► Lens Opacities
Retinal Damage

► Destruction of retinal nerves/vessels

► Permanent blind spot
  - May be unnoticed
    ► Small, periphery, area of overlapping vision
  - Aware
    ► Larger, in macula
Laser Injuries - ALPA Experience

► Instructed to call if injured

► 37 pilots reported injuries (5 years)
  - All green lasers
  - Most have afterimages, sensitivity
  - Effects resolve in 1-3 days (5 cases)

► One disabled > 24 months
  - Macular burn - reduced visual acuity
  - VA returned, persistent night sensitivity
Laser Effects & Injuries

- **Permanent Effects Unlikely**
  - Distant moving target
  - Educated aware pilot population

- **Temporary Effects Growing Threat**
  - Immediate Safety Threat
  - Psychological impact uncertain
  - Higher power, Easy availability
Visual effect hazards, and hazard distances, of a 5 milliwatt green laser pointer

Inset photos were taken in an FAA flight simulator. They show what a pilot sees on landing approach, during a 5 mW laser illumination. The closer the aircraft is to the laser, the more difficult it is to see out the windshield.

To calculate hazard distances for more powerful lasers, multiply the hazard distance by the square root of the power increase. For example, a 125 mW laser pointer is 25 times more powerful than the 5 mW laser shown here. The square root of 25 is 5. Therefore, the maximum Glare/Disruption Hazard Distance for a 125 mW laser is 5 x 1,200 ft, or 6,000 ft (over 1 mile). The maximum Distraction Hazard Distance is 5 x 11,700 ft, or 58,500 ft (11 miles).
<table>
<thead>
<tr>
<th>Laser power</th>
<th>Maximum eye hazard distance, feet / meters</th>
<th>Maximum flashblindness hazard distance, feet / meters</th>
<th>Max. glare/disruption hazard distance, feet / meters</th>
<th>Maximum distraction hazard distance, feet / meters</th>
<th>“Safe” distance (laser is not considered a distraction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 mW</td>
<td>52 / 16</td>
<td>260 / 80</td>
<td>1200 / 366</td>
<td>11700 / 3560</td>
<td>Beyond 2.2 miles</td>
</tr>
<tr>
<td>50 mW</td>
<td>164 / 50</td>
<td>822 / 250</td>
<td>3794 / 1156</td>
<td>36995 / 11276</td>
<td>Beyond 7 miles</td>
</tr>
<tr>
<td>125 mW</td>
<td>260 / 79</td>
<td>1300 / 396</td>
<td>6000 / 1829</td>
<td>58500 / 17830</td>
<td>Beyond 11 miles</td>
</tr>
<tr>
<td>250 mW</td>
<td>368 / 112</td>
<td>1838 / 560</td>
<td>8485 / 2586</td>
<td>82730 / 25216</td>
<td>Beyond 15.7 miles</td>
</tr>
<tr>
<td>500 mW (1/2 watt)</td>
<td>520 / 160</td>
<td>2600 / 800</td>
<td>12000 / 3660</td>
<td>117000 / 35600</td>
<td>Beyond 22.2 miles</td>
</tr>
</tbody>
</table>
## What’s on the Market?

**www.WickedLasers.com**

<table>
<thead>
<tr>
<th>Model</th>
<th>Power</th>
<th>Color</th>
<th>Battery</th>
<th>Cost</th>
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<tbody>
<tr>
<td>Core</td>
<td>5 mW</td>
<td>R</td>
<td>2x AA</td>
<td>$30</td>
</tr>
<tr>
<td>e2</td>
<td>75 mW</td>
<td>RGM</td>
<td>2x AAA</td>
<td>$60</td>
</tr>
<tr>
<td>e3</td>
<td>300 mW</td>
<td>RGM</td>
<td>2x AAA</td>
<td>$90</td>
</tr>
<tr>
<td>Spyder</td>
<td>1,000mW</td>
<td>GB</td>
<td>Lithium</td>
<td>$300</td>
</tr>
</tbody>
</table>

“Over 8,000 times brighter than the sun. Introducing the world's brightest laser you can legally own.”
Wicked Lasers

TORCH 100 W (100,000 mW)
Melts Plastics
Burns Paper
Lights Matches
Lights Cigarettes
Scrambles Eggs
$149.95
Protection

► Military LEP - specific wavelength only

► Not Protective
  - Windscreens
  - Glasses

► Behaviors / Pilot Actions
Recommendations for Event

- Blink reflex
- Turn away / heads down
- Shield / block source
- Turn up cockpit lighting
- Don’t rub eyes
- Report to authorities
- Get exam if any symptoms on ground
Laser Eye Exam

- History of Event
- Visual Acuity
- Amsler Grid
- Slit Lamp Exam of Cornea / Lens
- Color Vision
- Retinal Exam (dilated)
- Fundoscopic Photography
Resources

- ALPA Guidance pamphlet
  - Laser Illumination Threat Mitigation

- ICAO Document 9815
  - Manual on laser emitters & flight safety

- Pilot Safety Brochure (FAA AAM-400-10-3)
  - Laser Hazards in Navigable Airspace
Aircraft Accidents & Incidents Associated with Visual Disturbances from Bright Lights During Nighttime Flight Ops

A Review of Recent Laser Illumination Events in the Aviation Environment
The Effect of Laser Illumination on Operational and Visual Performance of Pilots during Final Approach

Laser Pointers: Their Potential Affects on Vision and Aviation Safety
Resources

► FAA Advisory Circular AC 70-2
  - Reporting of Laser Illumination of Aircraft

► Transport Canada Aeronautical Information Circular (AIC) 14/09
  - Pilot Procedures for Exposure to Laser and Other Bright Light Sources
Resources

► Managing Retinal Eye Injuries from Lasers
  ▪ American Academy of Ophthalmology Eye/Net

► Prevention and Medical Management of Laser Injuries
  ▪ US Army Field Manual 8-50

► USAF Laser Injury Guidebook
www.LaserPointerSafety.com

Aviation Specific section

USAF/FAA video

“Aircraft Laser Illumination”

Resources

► Houston S. Aircrew Exposure to Handheld Laser Pointers: The Potential for Retinal Damage
Aviat Space Environ Med 2011; 82:921-2
  • NOHD for 2000mW green laser = 1026 ft.
► FAA Vision Research Team - AAM-630
  • Van Nakagawara, Robert Montgomery
► FDA Radiation Emitting Products
Photograph Credits

► FAA Office of Aerospace Medicine
► National Eye Institute of National Institutes of Health
► LaserPointerSafety.com
► US Air Force
► NASA
Laser Injuries

“For God’s sake, Edwards. Put the laser pointer away.”
LASER ILLUMINATIONS OF AIRCRAFT - A GROWING THREAT

Laser Vision Injuries
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