

LASER 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

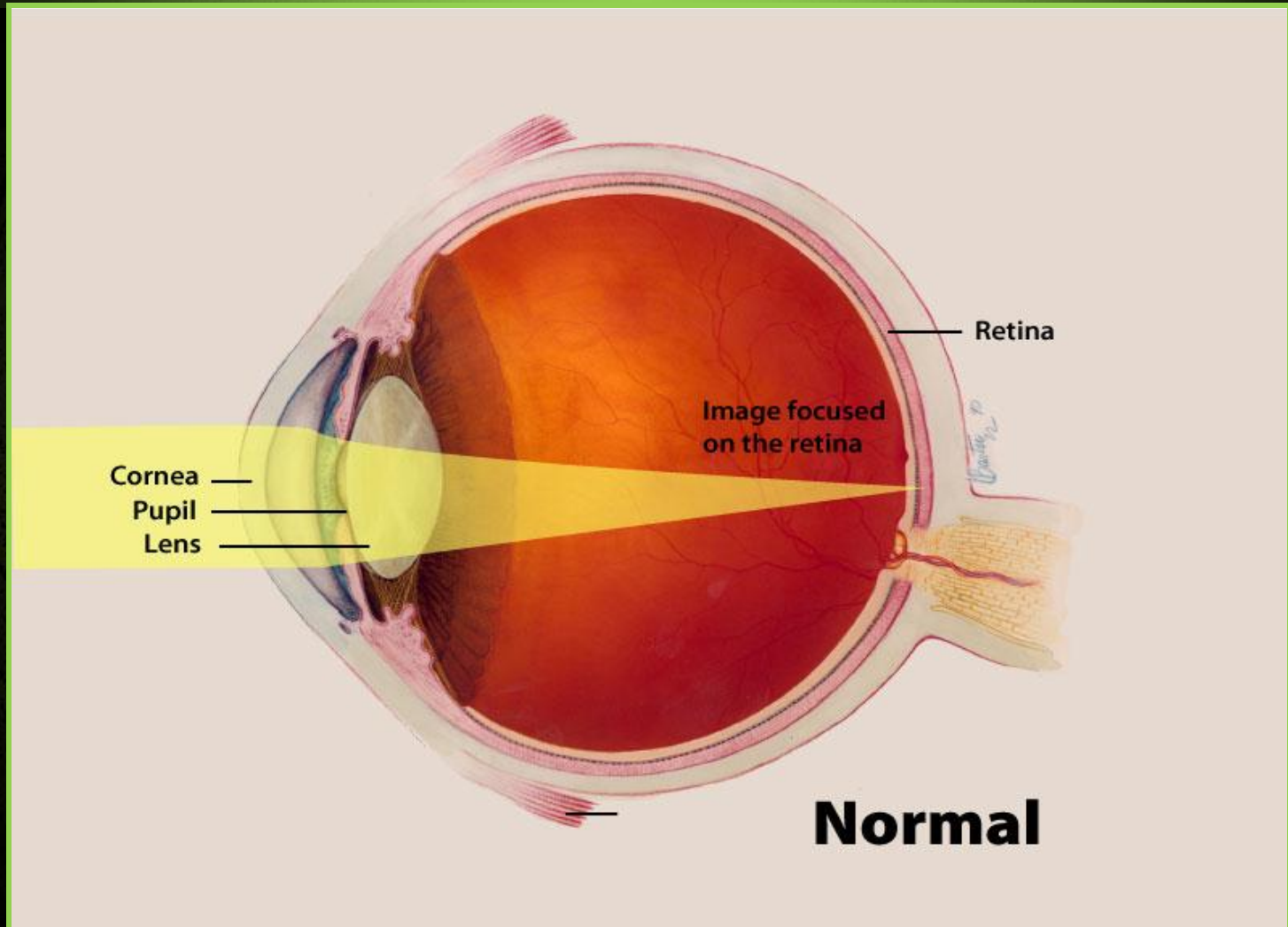


Eye Anatomy

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



Eye Anatomy



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



475 510 570 650

Wavelength [nm]

Green



475 510 570

Wavelength [nm]

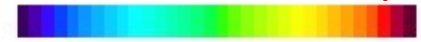
Yellow



475 510 570 650

Wavelength [nm]

Red

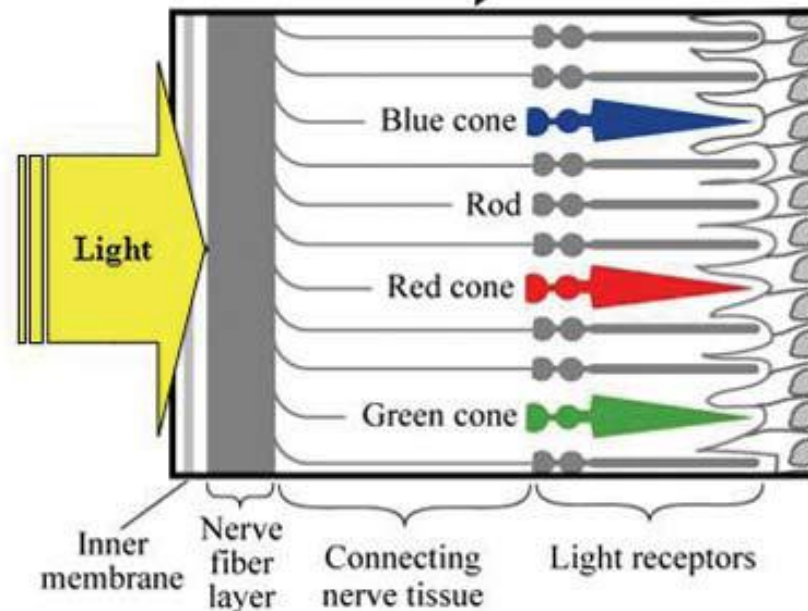
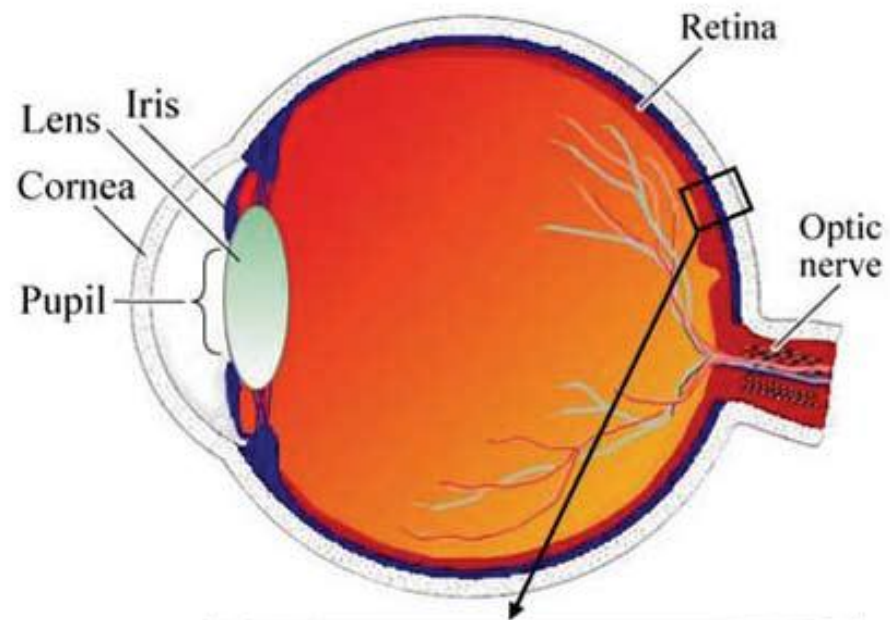


475 510 570 650

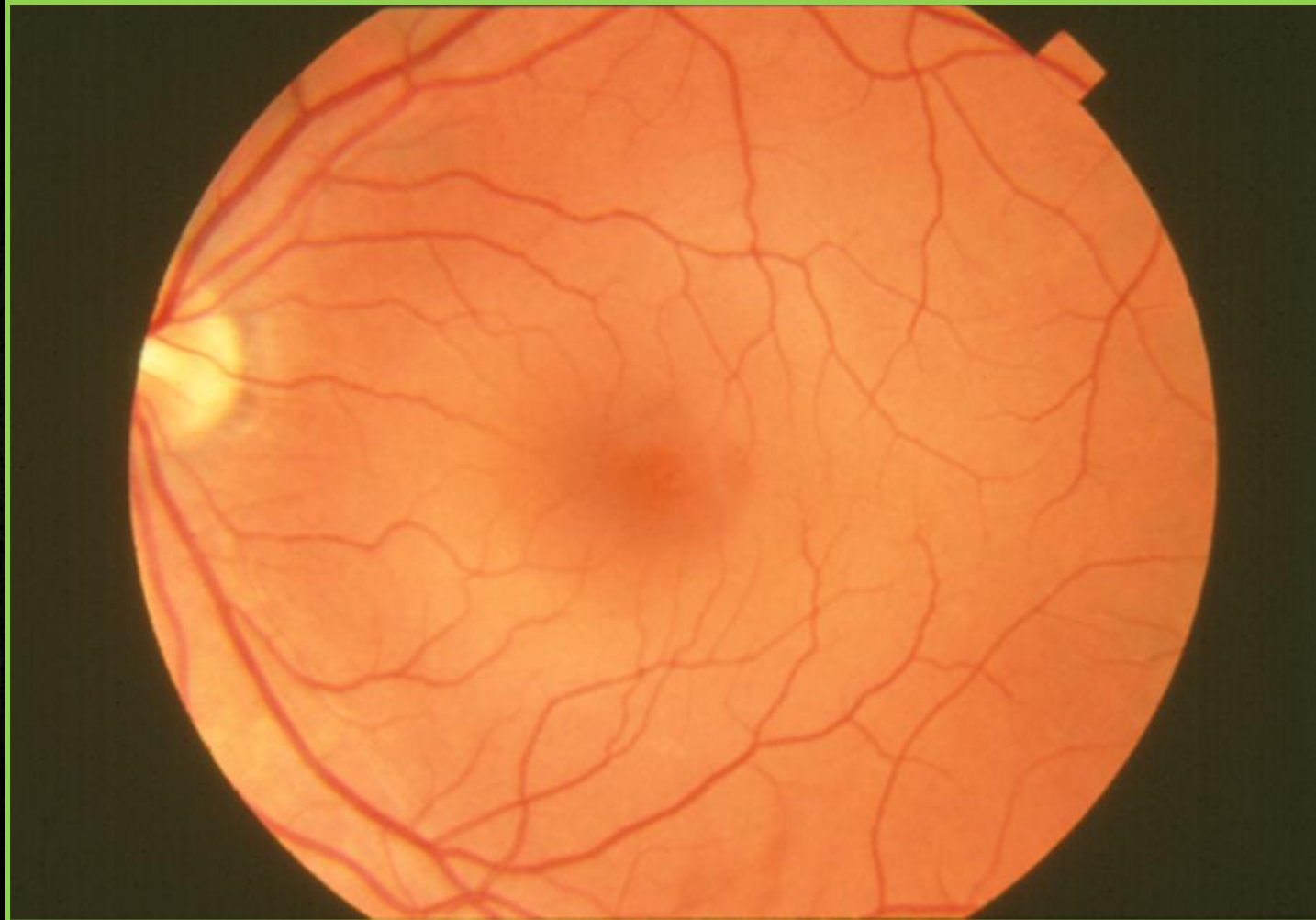
Wavelength [nm]



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Retina



Physiology

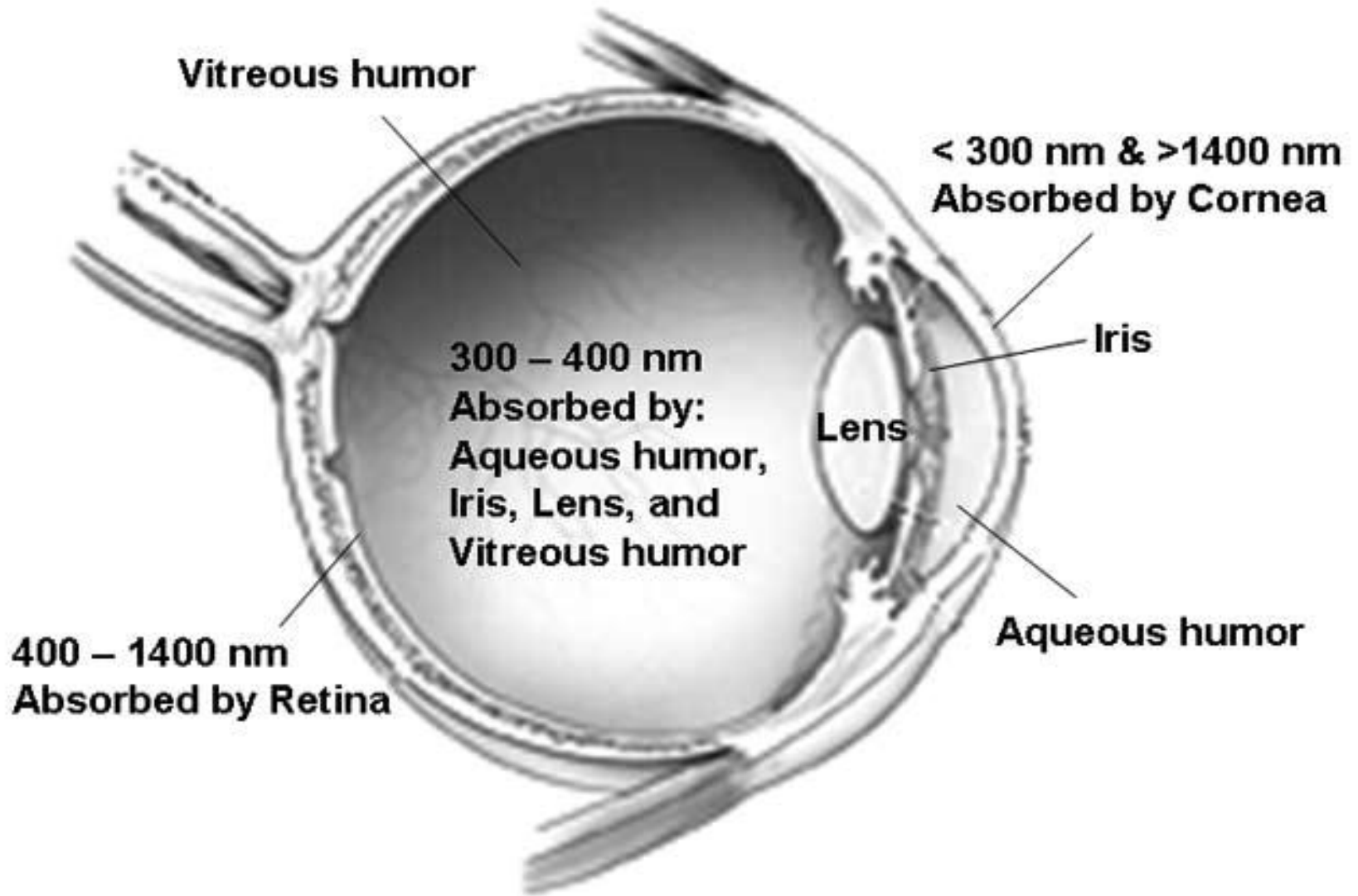
- ▶ Brain perceives visible light
- ▶ Eye exposed to IR – visible – UV
- ▶ Eye 35x more sensitive (green vs. red)
- ▶ Retina damaged by IR energy / heat



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



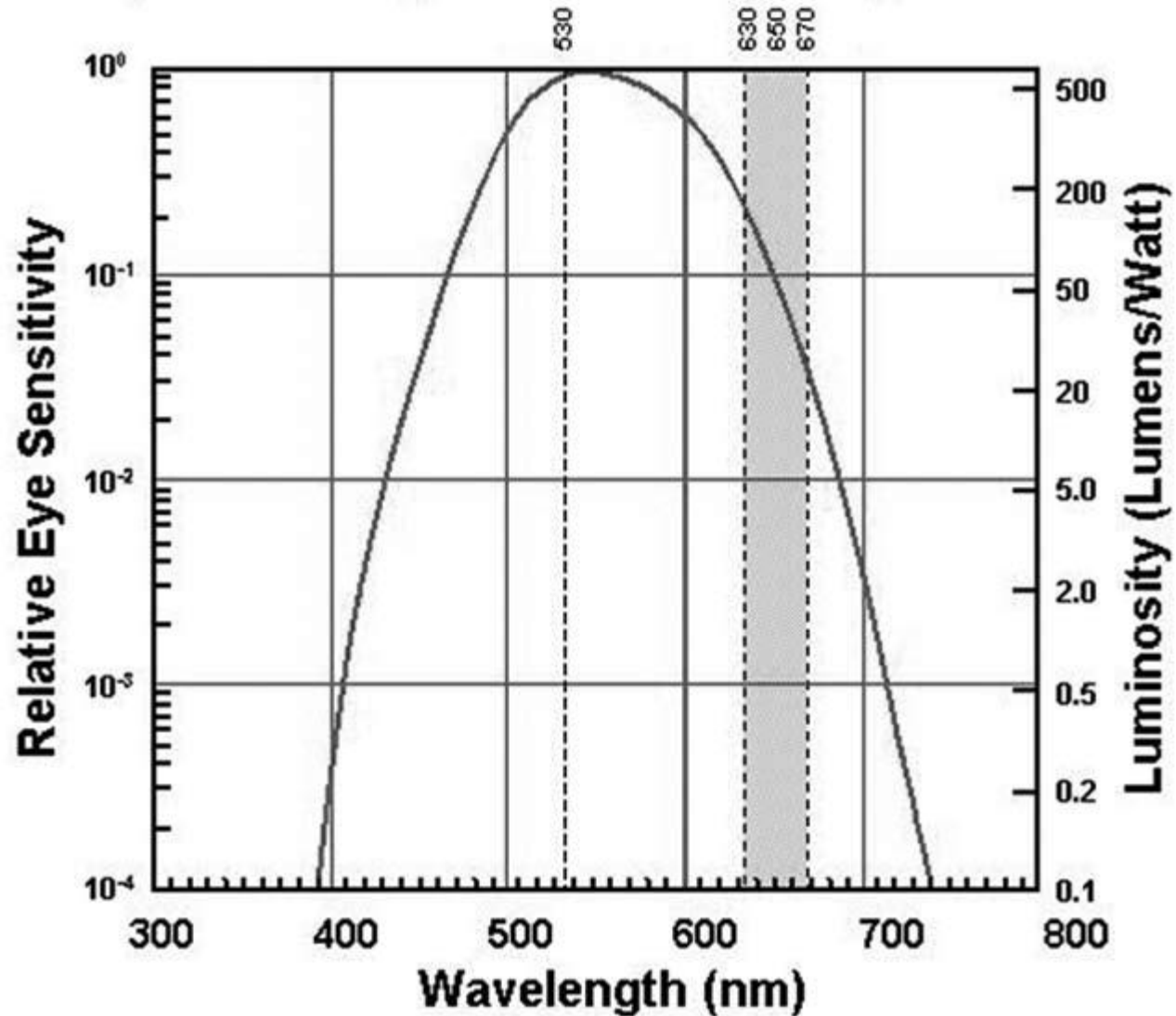


Sensitivity by Wavelength

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



Eye Sensitivity vs. Wavelength Dependence



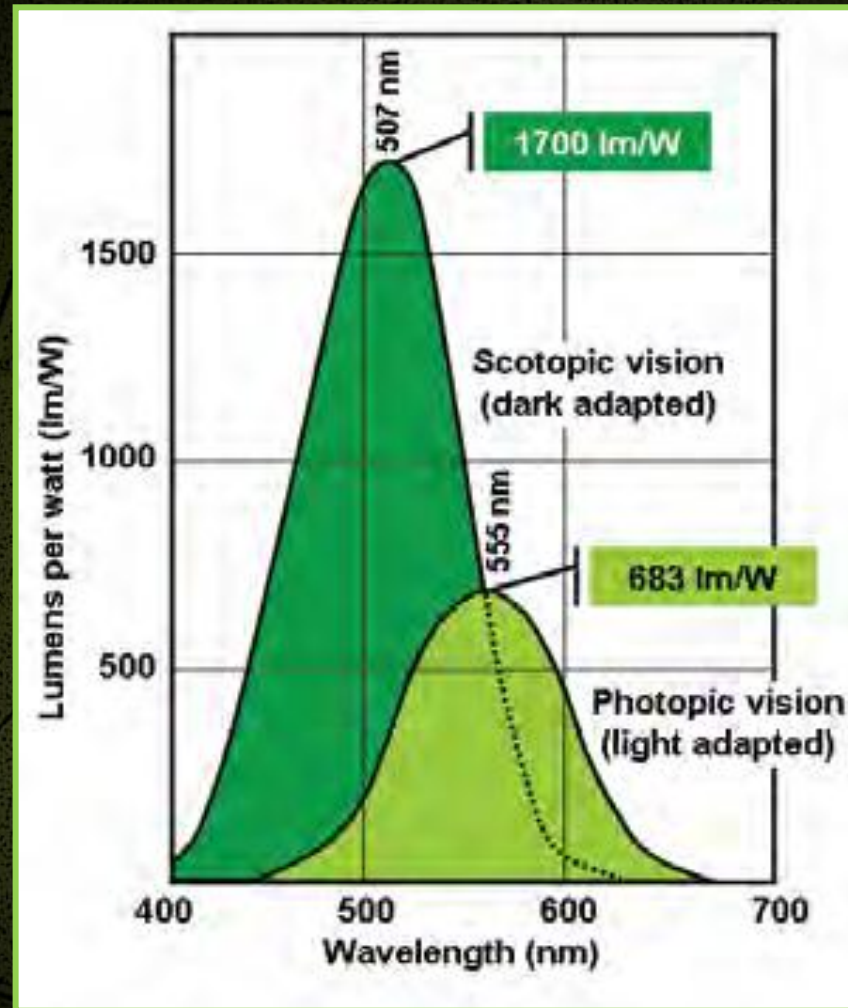
Physiology

► 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



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Therapeutic Eye Uses of Lasers

- ▶ Diabetic Retinopathy
- ▶ Glaucoma
- ▶ LASIK
- ▶ Others





Diabetic Retinopathy



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Laser Hazard Factors

- ▶ Laser Characteristics
- ▶ Laser Usage
- ▶ External Factors
- ▶ Protective Measures



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Laser Characteristics

- ▶ Power Output
- ▶ Wavelength
 - Color (Visible light)
 - IR / UV components (Non-visible)
- ▶ Divergence
- ▶ Pulse vs. Continuous



Classes of Lasers

Class

Power

Uses

1

$< 0.5 \text{ mW}$



2

$0.5\text{-}1.0 \text{ mW}$

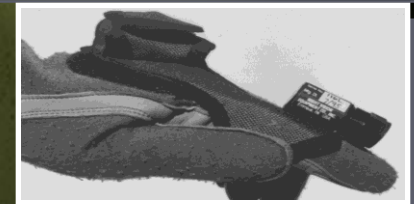


3a

$1 - 5 \text{ mW}$

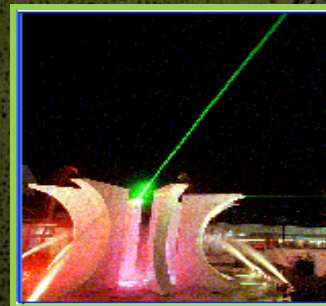
3b

$5 - 500 \text{ mW}$



4

$> 500 \text{ mW}$



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Laser Usage

- ▶ Direct vs. Indirect Illumination
- ▶ Daytime vs. Nighttime
- ▶ Distance to Aircraft
- ▶ Phase of Flight



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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 ($< \text{MPE}$)
 - 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



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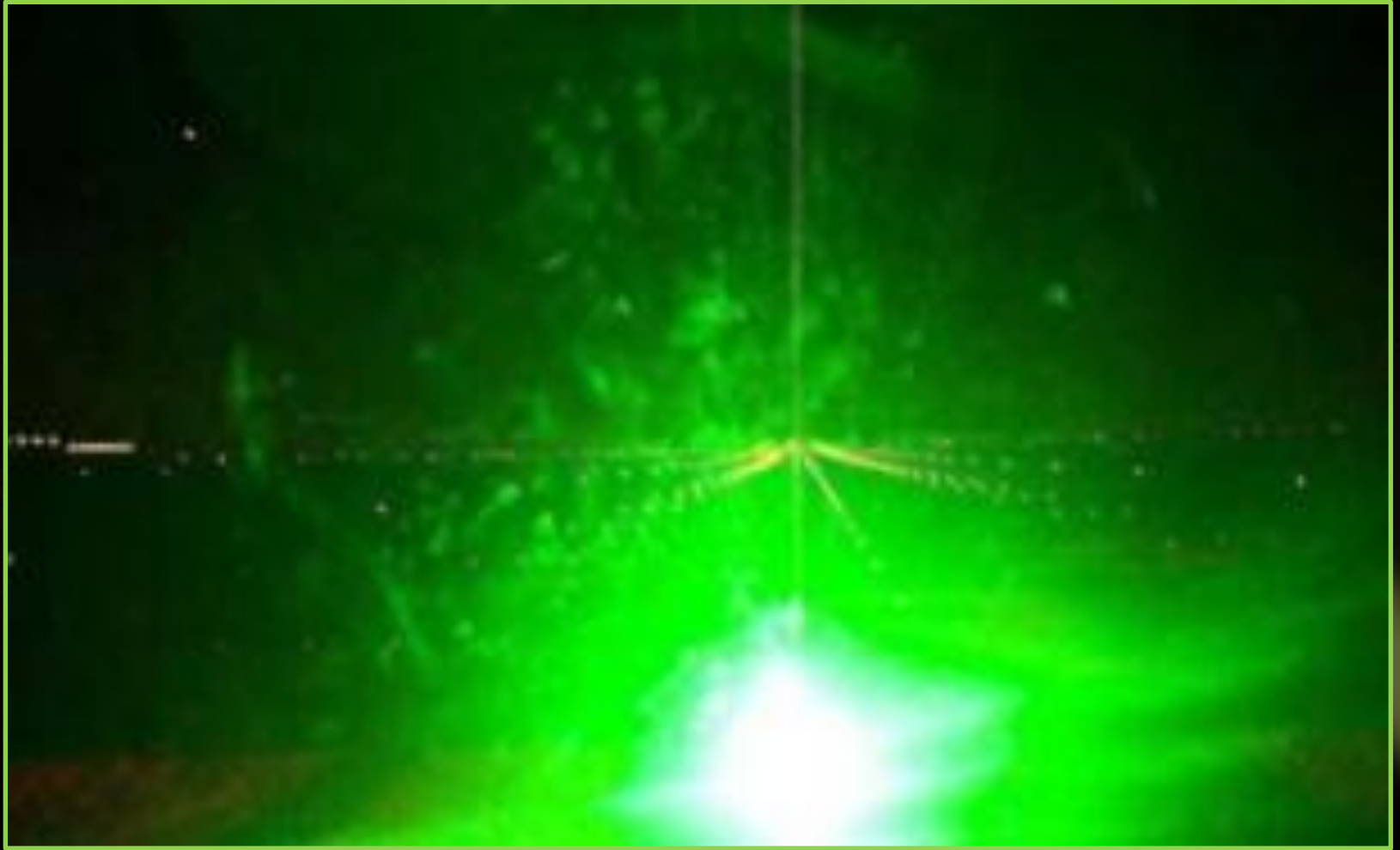
Distraction - $0.5 \mu\text{W} / \text{cm}^2$



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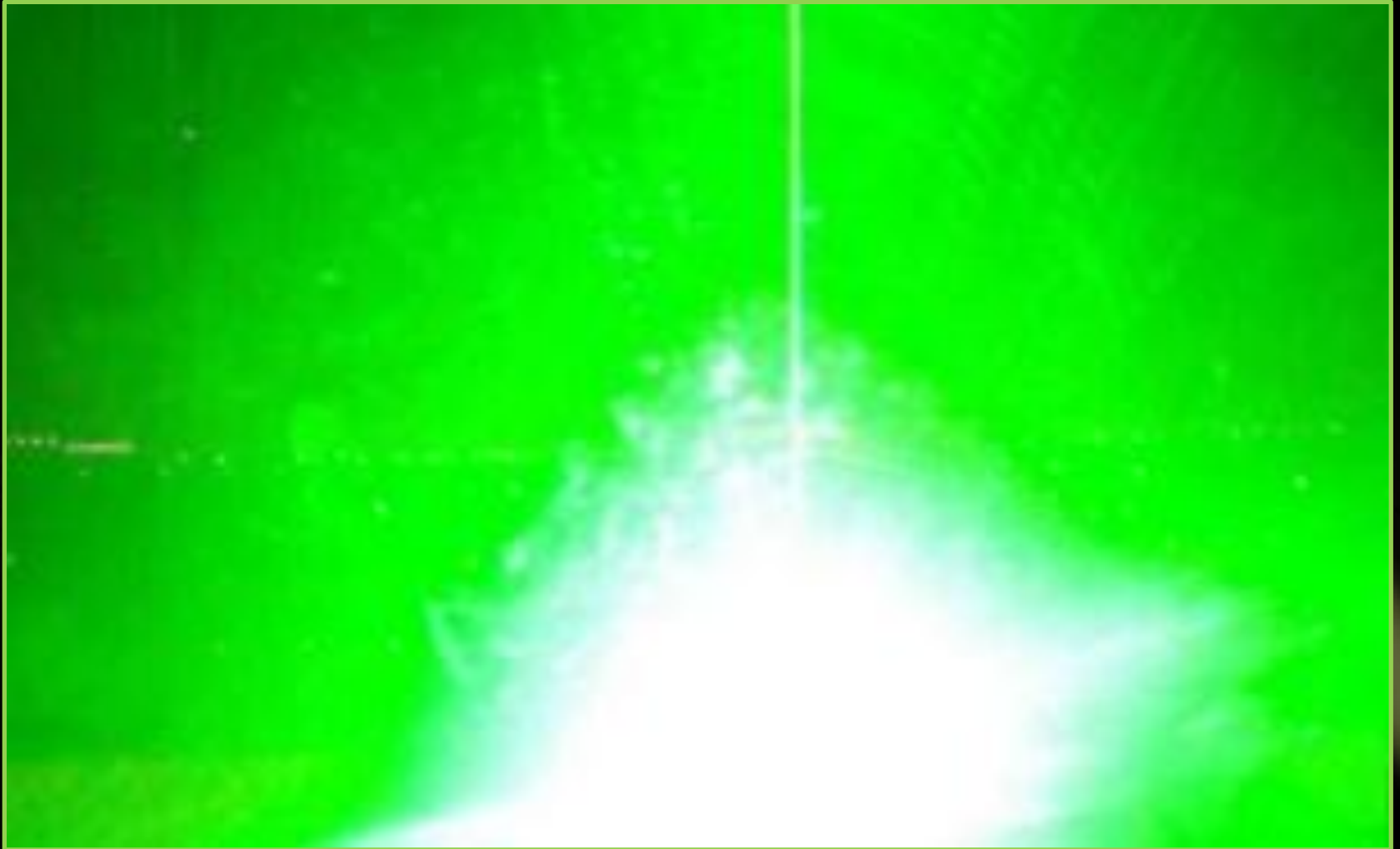
Glare - $5.0 \mu\text{W} / \text{cm}^2$



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Flash Blindness - 50 μW / cm^2



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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



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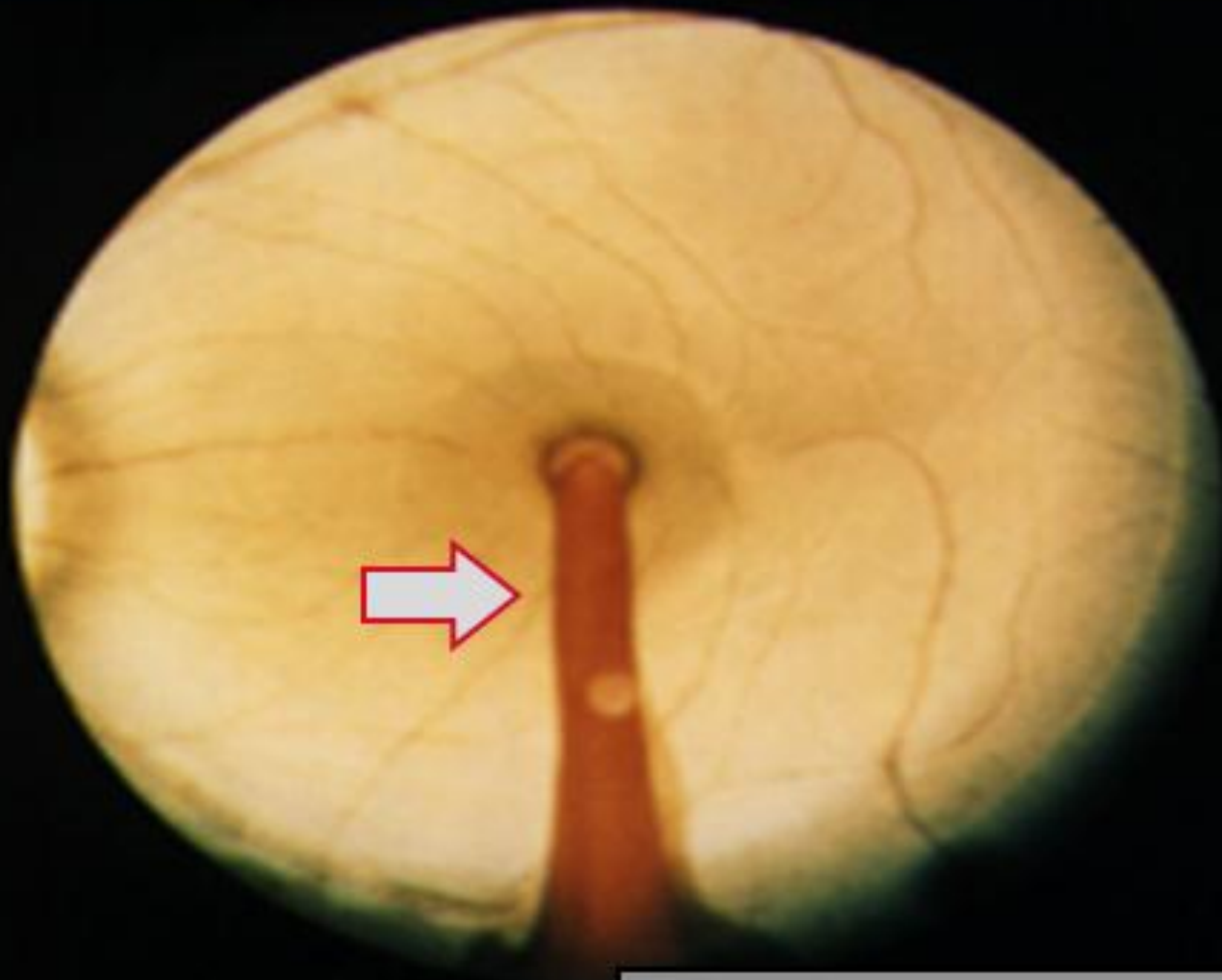
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Retinal Damage

- ▶ Destruction of retinal nerves/vessels
- ▶ Permanent blind spot
 - May be unnoticed
 - ▶ Small, periphery, area of overlapping vision
 - Aware
 - ▶ Larger, in macula





Retinal Hemorrhage



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

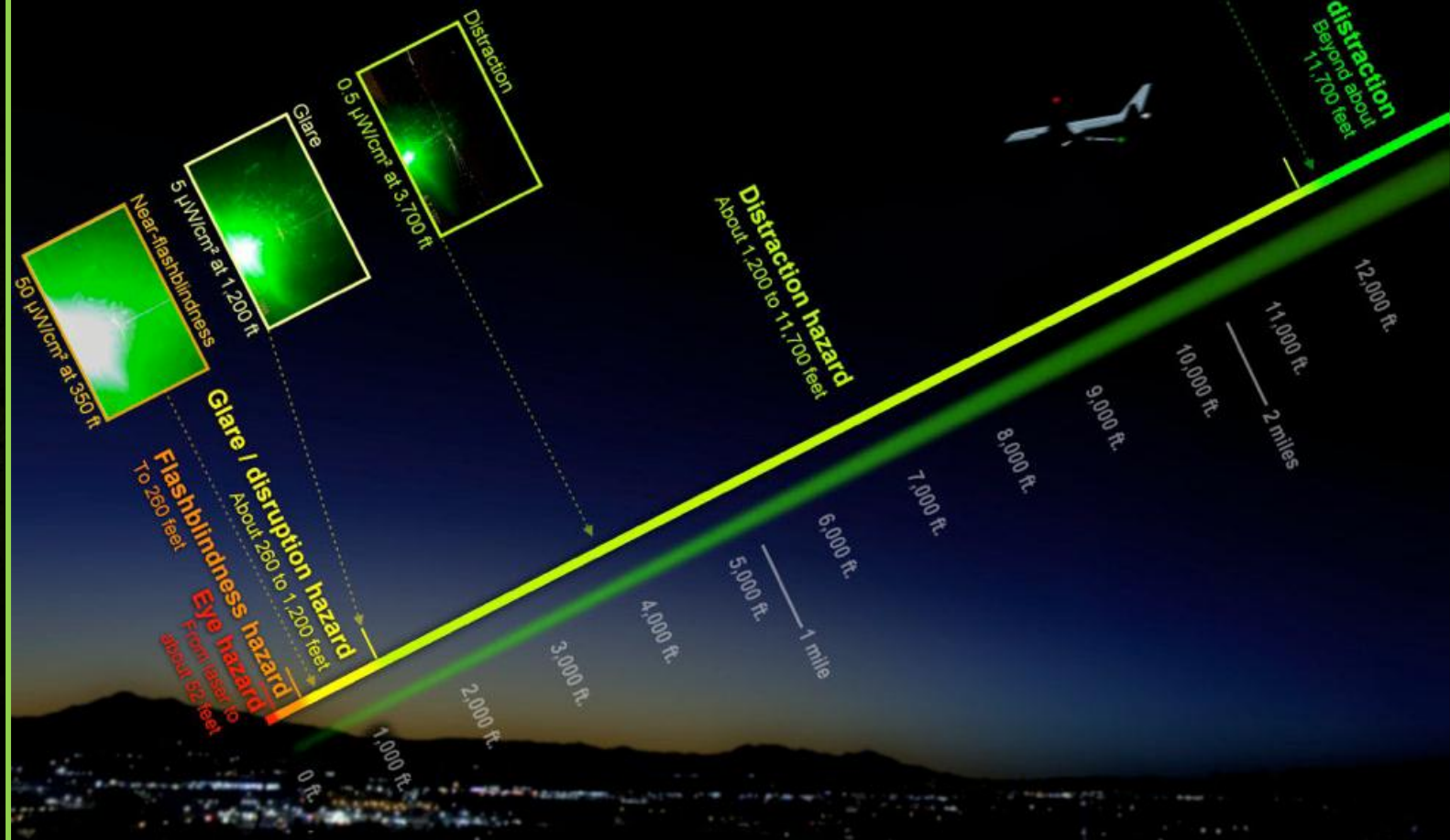
- ▶ Permanent Effects Unlikely
 - Distant moving target
 - Educated aware pilot population
- ▶ Temporary Effects Growing Threat
 - Immediate Safety Threat
 - Psychological impact uncertain
 - Higher power, Easy availability



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 windscreen.

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 $5 \times 1,200$ ft, or 6,000 ft (over 1 mile). The maximum Distraction Hazard Distance is $5 \times 11,700$ ft, or 58,500 ft (11 miles).



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Eye and visual hazard distances for 532 nm (green) lasers of various powers

Laser power	Maximum eye hazard distance, feet / meters	Maximum flashblindness hazard distance, feet / meters	Max. glare/disruption hazard distance, feet / meters	Maximum distraction hazard distance, feet / meters	"Safe" distance (laser is not considered a distraction)
5 mW	52 / 16	260 / 80	1200 / 366 1/4 mile	11700 / 3560 2.2 miles	Beyond 2.2 miles
50 mW	164 / 50	822 / 250	3794 / 1156 7/10 mile	36995 / 11276 7 miles	Beyond 7 miles
125 mW	260 / 79	1300 / 396	6000 / 1829 1.1 miles	58500 / 17830 11 miles	Beyond 11 miles
250 mW	368 / 112	1838 / 560	8485 / 2586 1.6 miles	82730 / 25216 15.7 miles	Beyond 15.7 miles
500 mW (1/2 watt)	520 / 160	2600 / 800	12000 / 3660 2.3 miles	117000 / 35600 22.2 miles	Beyond 22.2 miles



What's on the Market?

www.WickedLasers.com

<u>Model</u>	<u>Power</u>	<u>Color</u>	<u>Battery</u>	<u>Cost</u>
Core	5 mW	R	2x AA	\$ 30
e2	75 mW	RGM	2x AAA	\$ 60
e3	300 mW	RGM	2x AAA	\$ 90
Spyder	1,000mW	GB	Lithium	\$300

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



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Wicked Lasers

TORCH 100 W (100,000 mW)

Melts Plastics

Burns Paper

Lights Matches

Lights Cigarettes

Scrambles Eggs

\$149.95



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Protection

- ▶ Military LEP - specific wavelength only
- ▶ Not Protective
 - Windscreens
 - Glasses
- ▶ Behaviors / Pilot Actions



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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





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A

20/200

36

D F

20/100

24

H Z P

20/70

18

T X U D

20/50

12

Z A D N H

20/40

9

P N T U H X

20/30

6

U A Z N F D T

20/25

5

N P H T A F X U

20/20

4

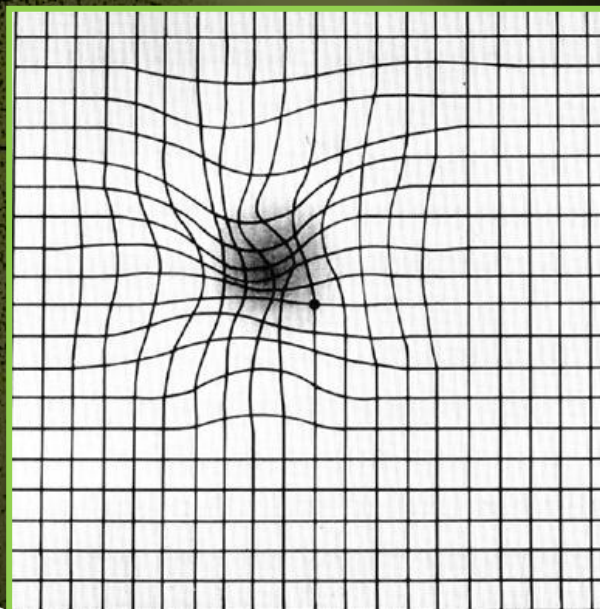
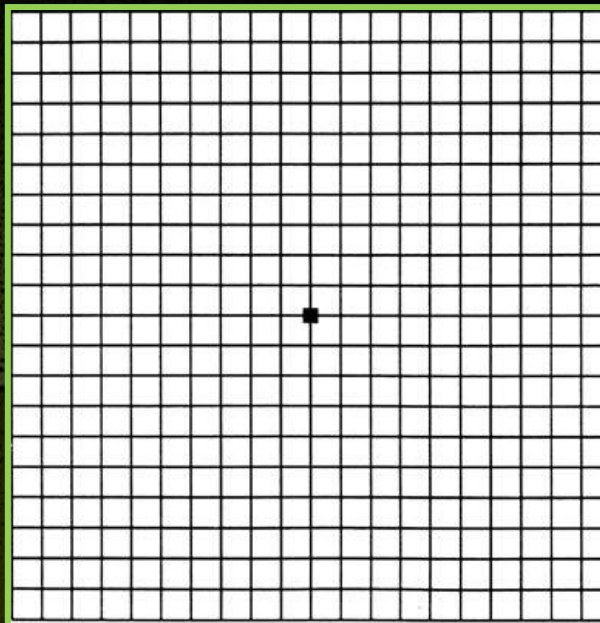
X D F H P T Z A N

20/15

3

F A X T D N H U P Z

20/10



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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*



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FAA Technical Reports

- ▶ DOT/FAA/AAM-06/28
 - Aircraft Accidents & Incidents Associated with Visual Disturbances from Bright Lights During Nighttime Flight Ops
- ▶ DOT/FAA/AAM-06/23
 - A Review of Recent Laser Illumination Events in the Aviation Environment



FAA Technical Reports

- ▶ DOT/FAA/AAM-04/9
 - The Effect of Laser Illumination on Operational and Visual Performance of Pilots during Final Approach

- ▶ DOT/FAA/AAM-01/7
 - 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



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www.LaserPointerSafety.com

Aviation Specific section

USAF/FAA video

“Aircraft Laser Illumination”

[http://laserpointersafety.com/page52/
2009FAAvideo/2009FAAvideo.html](http://laserpointersafety.com/page52/2009FAAvideo/2009FAAvideo.html)



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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



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Laser Injuries



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Questions?



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