Simple Self-Triage for Aircrew Post Handheld Laser Exposure

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Objectives

Handheld laser properties

Prove they are not a threat to vision while flying

Self- Assessment for aircrew and algorithm for providers

Special considerations

Ultimately stop: “Hey, doc! We were lazed at flight level 180. The entire crew is asymptomatic, but we need to be evaluated *right now* at 0300.”

LASER

Acronym: Light Amplification by Stimulated Emission of Radiation

Coherent and Directional

Ubiquitous: class room, astronomy, guns

Irradiance

Power Density = Power/(πr^2) = irradiance

Helps determine hazard distances

Power and beam divergence

Nominal Ocular Hazard Distance (NOHD)

Distance at which beam irradiance falls below $2.5 mW/cm^2$

Maximum Permissible Exposure (MPE)

Inadvertent exposure where the average person would blink and turn away in 0.25s, which is the blink reflex

Nominal Ocular Hazard Distance

At NOHD the laser is at MPE

MPE is set to be 1/10 ED_{50}

ED_{50} : effective dose at 50% population (in this case smallest detectable damage to retina)

Nominal Ocular Hazard Distance

Eye damage does not occur at NOHD!

NOHD concept includes a built-in safety margin

- MPE is 1/10 ED_{50}
- ED_{50} is at roughly 1/3rd the distance of NOHD (31.6%)
- Damage to retina unlikely between ED_{50} and NOHD

Wavelength

Visible wavelength has no affect on NOHD

- Not a variable in the formula

Wavelength does affect visual interference

Wavelength

Most sensitive to green at 555nm

532nm green, most consumer lasers, 88% as bright

635nm red appears 27% as bright as 532nm green

532nm blue appears 3.5% bright as 532 nm green

Hazard distances for select… …sumer laser types and parameters (color, beam spread, and power)

LASER TYPE OR MODEL	BEAM COLOR Wavelength, nanometers	BEAM SPREAD Divergence, milliradians	LASER POWER, milliwatts	E… …NCE Nomina… …d Distance. Distance at w… …m irradiance falls below 2.5 m… …atts per sq. cm. Laser light in the FAA Normal Flight Zone must be below this level. NOHD in feet	NOHD in miles	NOHD in meters	FLASHBLINDNESS DISTANCE FAA Sensitive Flight Zone Exposure Distance. Distance at which beam irradiance falls below 100 microwatts per sq. cm. Laser light in the FAA Sensitive Flight Zone must be below this level. SFZED in feet	SFZED in miles	SFZED in meters
CLASS 2 (less than 1 mW)									
0.99 mW red pointer, typical beam spread	635	1.0	0.99	**23**	0.004	7.0	**55**	0.01	17
0.99 mW green pointer, typical beam spread	532	1.0	0.99	**23**	0.004	7.0	**109**	0.02	33
0.99 mW red pointer, tighter beam	635	0.5	0.99	**46**	0.009	14.1	**109**	0.02	33
0.99 mW green pointer, tighter beam	532	0.5	0.99	**46**	0.009	14.1	**218**	0.04	67
CLASS 3R (less than 5 mW)									
4.99 mW red pointer, typical beam spread	635	1.0	4.99	**52**	0.010	15.8	**123**	0.02	37
4.99 mW green pointer, typical beam spread	532	1.0	4.99	**52**	0.010	15.8	**245**	0.05	75
4.99 mW red pointer, tighter beam	635	0.5	4.99	**104**	0.020	31.6	**245**	0.05	75
4.99 mW green pointer, tighter beam	532	0.5	4.99	**104**	0.020	31.6	**490**	0.09	149
CLASS 3B (5 to <500 mW)									
50 mW green handheld, typical beam spread	532	0.5	50	**328**	0.062	100.0	**1,551**	0.29	473
250 mW green handheld, typical beam spread	532	0.7	250	**524**	0.099	159.7	**2,477**	0.47	755
499 mW green handheld, typical beam spread	532	1.0	499	**518**	0.098	157.9	**2,450**	0.46	747
CLASS 4 (500 mW and above)									
Wicked Lasers S3 Arctic, 700 mW	445	1.5	700	**409**	0.077	124.7	**360**	0.07	110
Wicked Lasers S3 Arctic, 1.4 Watts	445	1.5	1400	**579**	0.110	176.3	**509**	0.10	155
Wicked Lasers S3 Arctic, 2 Watts	445	1.5	2000	**691**	0.131	210.8	**609**	0.12	186
Wicked Lasers S3 Inferno, 750 mW	635	3.0	750	**212**	0.040	64.5	**501**	0.09	153
Wicked Lasers S3 Krypton, 500 mW	532	1.5	500	**346**	0.065	105.4	**1,635**	0.31	498
1 Watt green laser, typical beam spread	532	1.5	1000	**489**	0.093	149.0	**2,312**	0.44	705
2 Watt green laser, typical beam spread	532	1.5	2000	**691**	0.131	210.8	**3,269**	0.62	997
5 Watt green laser, typical beam spread	532	2.0	5000	**820**	0.155	249.9	**3,877**	0.73	1,182

LASER TYPE OR MODEL	GLARE DISTANCE FAA Critical Flight Zone Exposure Distance. Distance at which beam irradiance falls below 5 microwatts per sq. cm. Laser light in the FAA Critical Flight Zone must be below this level. CFZED in feet	CFZED in miles	CFZED in meters	DISTRACTION DISTANCE FAA Laser Free Flight Zone Exposure Distance. Distance at which beam irradiance falls below 50 nanowatts per sq. cm. Laser light in the FAA Laser Free Flight Zone must be below this level. LFFZED in feet	LFFZED in miles	LFFZED in meters	SKIN BURN HAZARD DISTANCE Distance at which laser can cause skin injury. In feet	In meters	FIRE HAZARD DISTANCE (From NFPA) In feet	In meters
CLASS 2 (less than 1 mW)										
0.99 mW red pointer, typical beam spread	**244**	0.0	74	**2,441**	0.5	744	**1.5**	0.5	**1.0**	0.3
0.99 mW green pointer, typical beam spread	**488**	0.1	149	**4,880**	0.9	1,487	**1.5**	0.5	**1.0**	0.3
0.99 mW red pointer, tighter beam	**488**	0.1	149	**4,881**	0.9	1,488	**3.1**	0.9	**2.0**	0.6
0.99 mW green pointer, tighter beam	**976**	0.2	297	**9,759**	1.8	2,975	**3.1**	0.9	**2.0**	0.6
CLASS 3R (less than 5 mW)										
4.99 mW red pointer, typical beam spread	**548**	0.1	167	**5,480**	1.0	1,670	**3.4**	1.0	**2.3**	0.7
4.99 mW green pointer, typical beam spread	**1,096**	0.2	334	**10,955**	2.1	3,339	**3.4**	1.0	**2.3**	0.7
4.99 mW red pointer, tighter beam	**1,096**	0.2	334	**10,959**	2.1	3,340	**6.9**	2.1	**4.6**	1.4
4.99 mW green pointer, tighter beam	**2,191**	0.4	668	**21,910**	4.1	6,678	**6.9**	2.1	**4.6**	1.4
CLASS 3B (5 to <500 mW)										
50 mW green handheld, typical beam spread	**6,936**	1.3	2,114	**69,356**	13.1	21,140	**21.7**	6.6	**14.5**	4.4
250 mW green handheld, typical beam spread	**11,078**	2.1	3,376	**110,775**	21.0	33,764	**34.7**	10.6	**23.1**	7.0
499 mW green handheld, typical beam spread	**10,955**	2.1	3,339	**109,552**	20.7	33,392	**34.3**	10.5	**22.9**	7.0
CLASS 4 (500 mW and above)										
Wicked Lasers S3 Arctic, 700 mW	**1,610**	0.3	491	**16,103**	3.0	4,908	**27.1**	8.3	**18.1**	5.5
Wicked Lasers S3 Arctic, 1.4 Watts	**2,277**	0.4	694	**22,773**	4.3	6,941	**38.3**	11.7	**25.5**	7.8
Wicked Lasers S3 Arctic, 2 Watts	**2,722**	0.5	830	**27,219**	5.2	8,296	**45.8**	14.0	**30.5**	9.3
Wicked Lasers S3 Inferno, 750 mW	**2,239**	0.4	683	**22,393**	4.2	6,825	**14.0**	4.3	**9.3**	2.8
Wicked Lasers S3 Krypton, 500 mW	**7,311**	1.4	2,228	**73,108**	13.8	22,283	**22.9**	7.0	**15.3**	4.7
1 Watt green laser, typical beam spread	**10,339**	2.0	3,151	**103,390**	19.6	31,513	**32.4**	9.9	**21.6**	6.6
2 Watt green laser, typical beam spread	**14,622**	2.8	4,457	**146,216**	27.7	44,567	**45.8**	14.0	**30.5**	9.3
5 Watt green laser, typical beam spread	**17,339**	3.3	5,285	**173,391**	32.8	52,850	**54.3**	16.6	**36.2**	11.0

How divergence affects hazard distances: If a laser's divergence (beam spread) is increased, the hazard distances directly decrease.

For example, doubling the divergence will reduce the hazard distances by half. Usually, the more powerful a laser, the larger the typical divergence of the laser. Divergence can be improved (made tighter) using a lens or better engineering of the laser itself.

How laser power affects hazard distances: If a laser's power is increased, the hazard distances are longer by the square root of the power increase.

Going from a 5 mW to a 500 mW laser is a 100 times power increase -- but the hazard distances only become 10 times as long. (The square root of 100 is 10.)

How wavelength affects hazard distances: For visible lasers, the wavelength (color) does not affect the eye hazard (NOHD), skin hazard or fire hazard distances. But wavelength does affect the three visual interference distances: Flashblindness, glare and distraction.

The human eye is most sensitive to green light of 555 nanometers. This color would appear brightest, and most distracting to pilots, compared to other colors from an otherwise equivalent laser (e.g., having the same power and divergence).

As of 2015, most consumer lasers emit green light at 532 nanometers. This appears only 88% as bright as 555 nm light. Because it is so common, we will use 532 green as the baseline for "brightest available laser" in the following calculations:

-- Compared with 532 nm light, the common red wavelength 635 nm appears only 27% as bright. This has a square root effect on the visual interference distances. A 532 green laser appears 4 times as bright as a 635 red laser -- but the green visual interference distances are only 2 times the red distances. (The square root of 4 is 2.)

-- Compared with 532 nm light, the common blue wavelength 445 nm appears only 3.5% as bright. Again, there is a square root effect on the distances. A 532 green laser appears 29 times as bright as a 445 blue laser -- but the green visual interference distances are only 5.4 times longer than the blue distances. (The square root of 29 is 5.4.)

Most powerful consumer handheld laser found through simple search engine

30W or 30,000mW

NOHD: 2678.1 Feet

ED_{50} : 847.5 Feet

So, outside of 1000 ft, eye damage is virtually impossible

FAA report 2011, 2012, 2015, 2016

4 years: 22,218 laser incidents

170 listed as one or more eye effects or injuries

Percent of incidents that actually had one or more eye effects or injuries reported: 0.77%

1 person claimed retinal damage (unable to verify based on data)

Reported Eye Effects

Flash blindness/blind spots/pain/burning/glare/blurred vision/headache/double vision/watering eye/distracted

Discrediting Some Effects

Pain: retinal disease is painless, laser absorption in the retina does not cause pain

- Cornea: plethora of nerve endings, however, visible light is not absorbed in the cornea, therefore no pain

Watery eyes/Itchiness:

- Tendency to rub eyes and/or hypervigilance
- This may lead to damaging the cornea and engendering pain

Most Important Reported

Distractions: result of flash blindness/glare

Common Bright Light Scenarios

Flash blindness from camera, slit lamp, ophthalmoscope

- Bright residual ‘spots’ that spontaneously resolve over the course of minutes
- Rhodopsin bleaching

Inadvertent laser pointer in office or class room

These don’t cause panic

Case Study

Deliberate and controlled exposure to eye prior to enucleation

- 3A green laser to the fovea of 55 yo woman with ring melanoma
- Took 60 seconds to produce damage
- Not happening to air crew

Self-Assessment

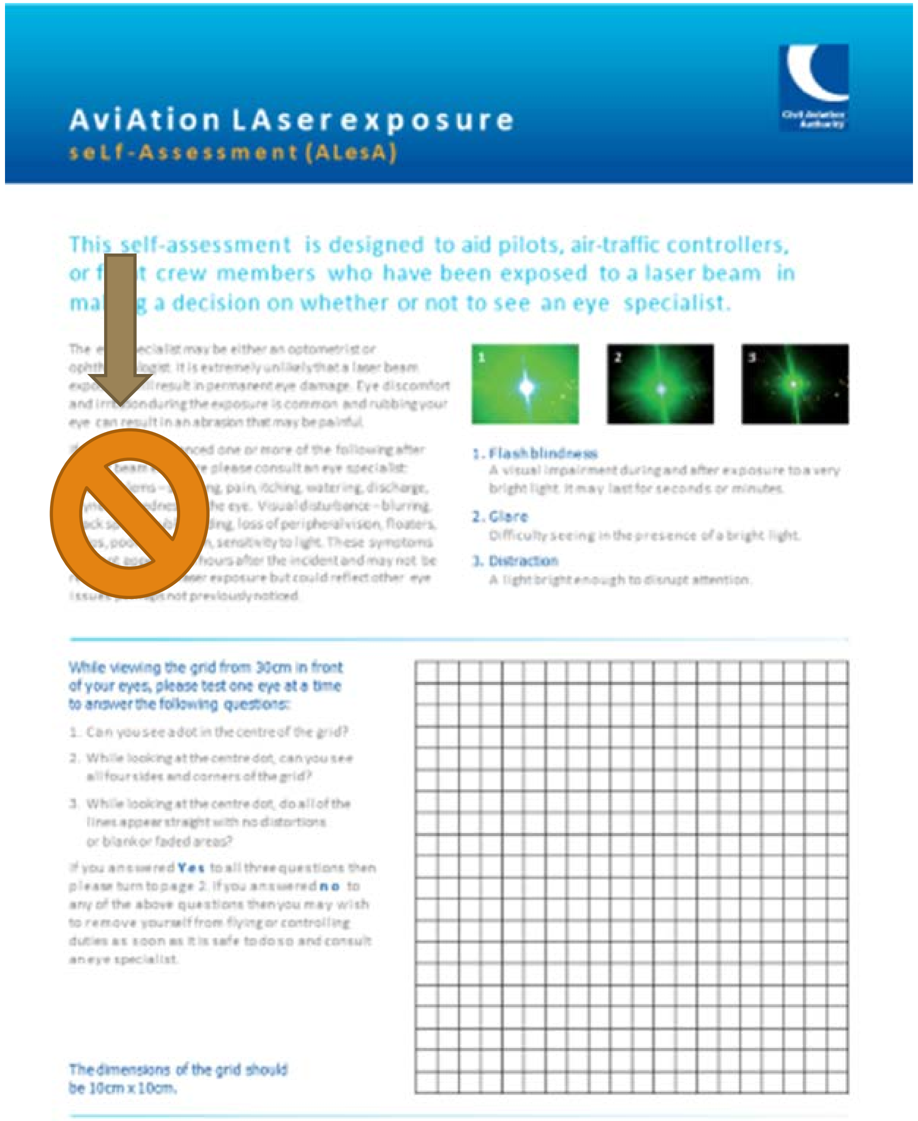
Before Any Self- Assessment

Maintain control of the aircraft!

Self-Assessment Example

British Civil Aviation Authority (CAA)

- Created an Aviation Laser Exposure Self-Assessment (ALESA)
- 2 page brochure with amsler grid and algorithm



AviAtion LAser exposure
seLf-Assessment (ALesA)

This self-assessment is designed to aid pilots, air-traffic controllers, or f[illegible]t crew members who have been exposed to a laser beam in ma[illegible]g a decision on whether or not to see an eye specialist.

The e[illegible]ecialist may be either an optometrist or ophth[illegible]logist. It is extremely unlikely that a laser beam expo[illegible]ill result in permanent eye damage. Eye discomfort and irr[illegible]on during the exposure is common and rubbing your eye can result in an abrasion that may be painful.

[illegible]nced one or more of the following after [illegible] beam [illegible]e please consult an eye specialist: [illegible]ions – [illegible]ng, pain, itching, watering, discharge, [illegible]dnes[illegible]he eye. Visual disturbance – blurring, [illegible]ck sp[illegible]ding, loss of peripheral vision, floaters, [illegible]s, poo[illegible]n, sensitivity to light. These symptoms [illegible] hours after the incident and may not be [illegible]aser exposure but could reflect other eye issues [illegible] not previously noticed.

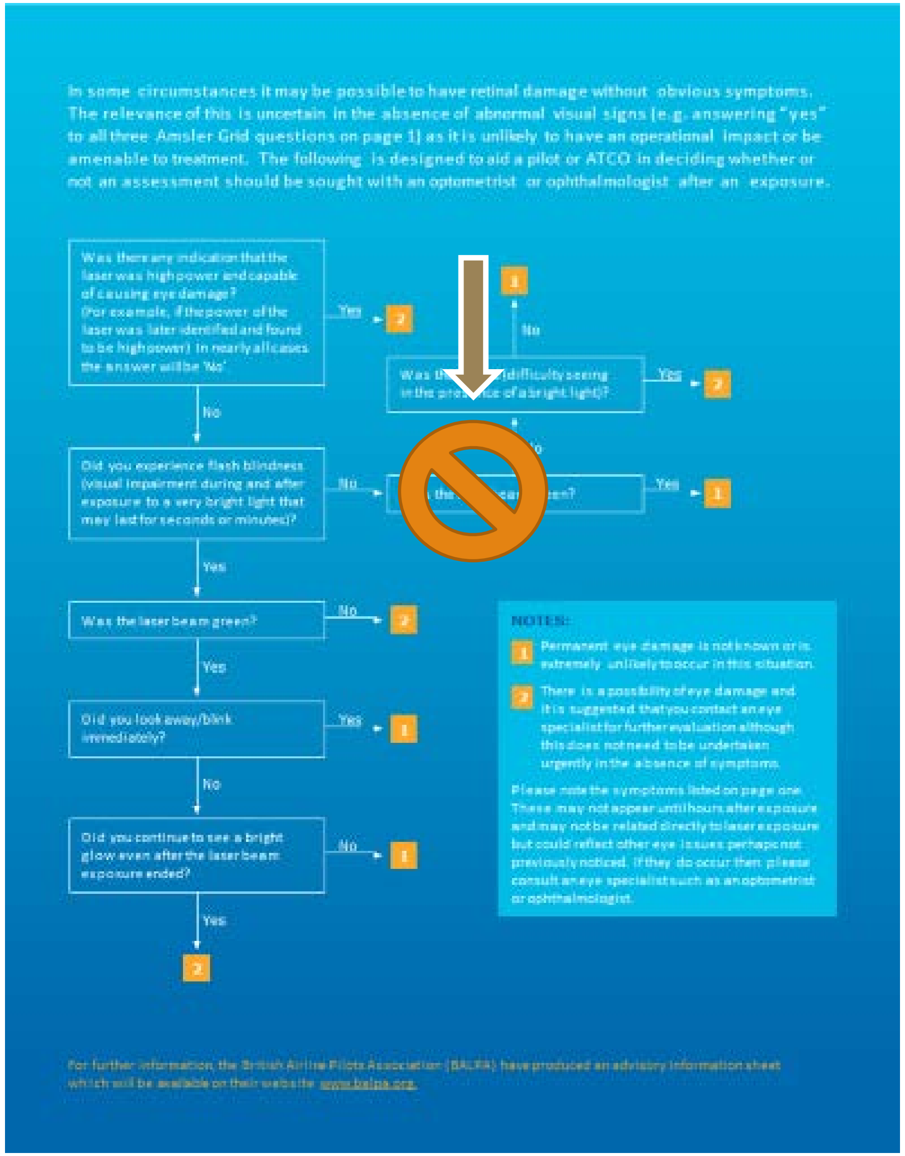
1. **Flash blindness**
   A visual impairment during and after exposure to a very bright light. It may last for seconds or minutes.
2. **Glare**
   Difficulty seeing in the presence of a bright light.
3. **Distraction**
   A light bright enough to disrupt attention.

While viewing the grid from 30cm in front of your eyes, please test one eye at a time to answer the following questions:

1. Can you see a dot in the centre of the grid?
2. While looking at the centre dot, can you see all four sides and corners of the grid?
3. While looking at the centre dot, do all of the lines appear straight with no distortions or blank or faded areas?

If you answered **Yes** to all three questions then please turn to page 2. If you answered **no** to any of the above questions then you may wish to remove yourself from flying or controlling duties as soon as it is safe to do so and consult an eye specialist.

The dimensions of the grid should be 10cm x 10cm.



In some circumstances it may be possible to have retinal damage without obvious symptoms. The relevance of this is uncertain in the absence of abnormal visual signs (e.g. answering "yes" to all three Amsler Grid questions on page 1) as it is unlikely to have an operational impact or be amenable to treatment. The following is designed to aid a pilot or ATCO in deciding whether or not an assessment should be sought with an optometrist or ophthalmologist after an exposure.

NOTES:

1 Permanent eye damage is not known or is extremely unlikely to occur in this situation.

2 There is a possibility of eye damage and it is suggested that you contact an eye specialist for further evaluation although this does not need to be undertaken urgently in the absence of symptoms.

Please note the symptoms listed on page one. These may not appear until hours after exposure and may not be related directly to laser exposure but could reflect other eye issues perhaps not previously noticed. If they do occur then please consult an eye specialist such as an optometrist or ophthalmologist.

For further information, the British Airline Pilots Association (BALPA) have produced an advisory information sheet which will be available on their website www.balpa.org.

Even Simpler

No symptoms…

…no problem!

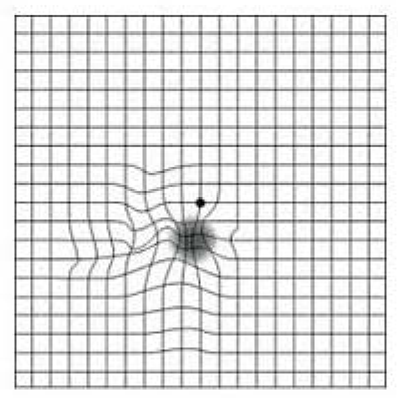
- Previously demonstrated that it is impossible to cause damage

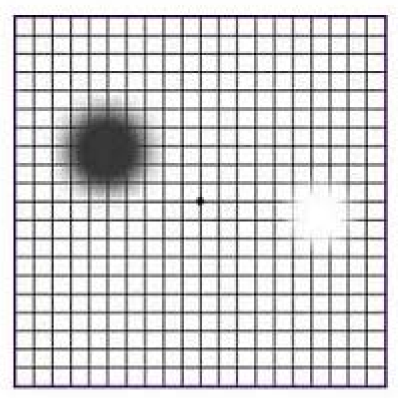
Aircrew still not convinced?

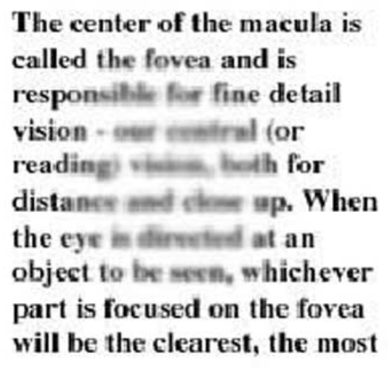
Amsler Grid: Useful

- What if aircrew doesn’t want to carry extra paperwork?

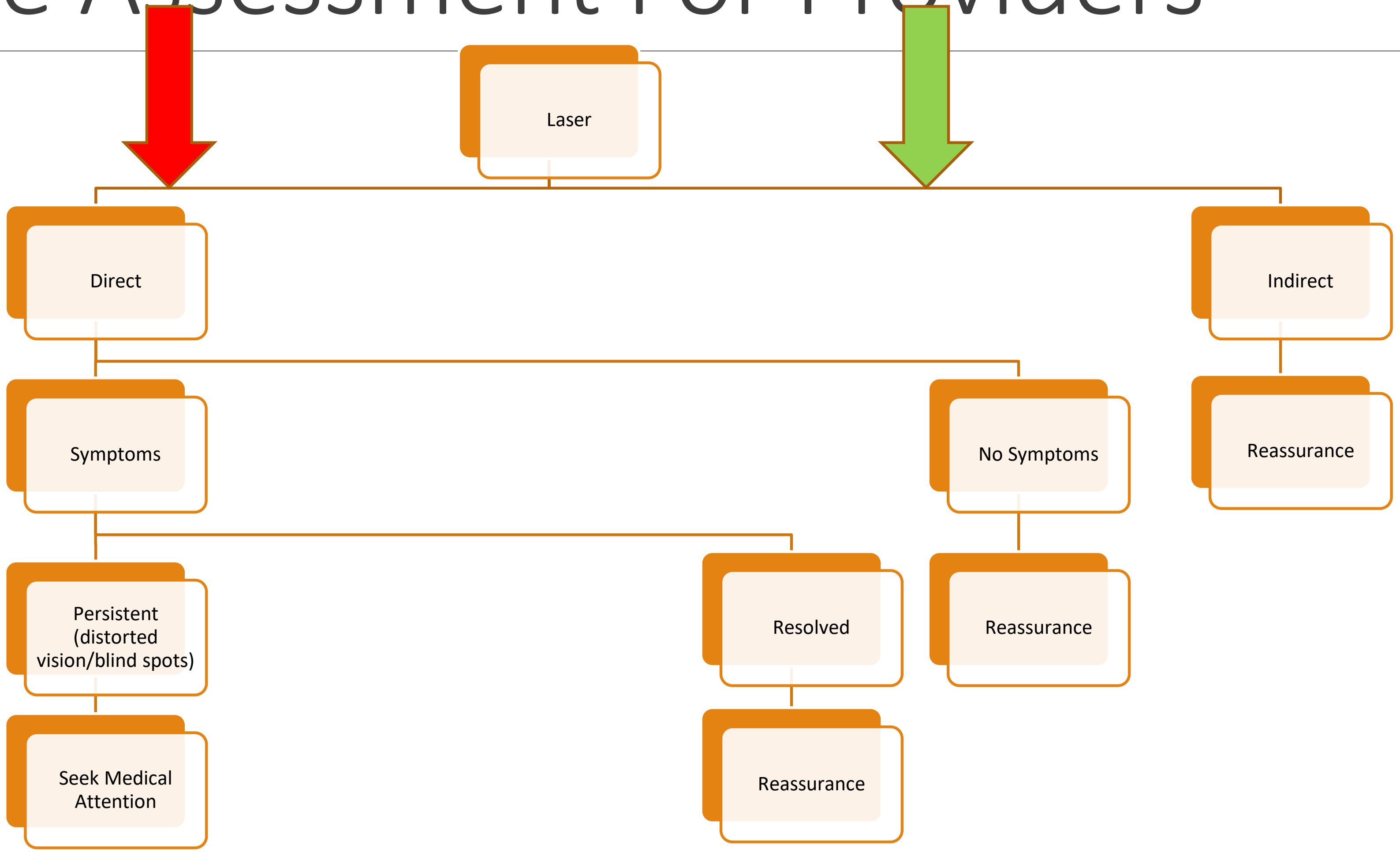
Reading: dash-1, HUD, literature: No significant central retina damage







Simple Assessment For Providers



Special Considerations

Night Vision Goggles

What if aircrew is wearing night vision goggles?

- Reassurance: the optics will ‘bloom out’, damaging the equipment

Caveat: Non-weaponized and Ground Based Attacks

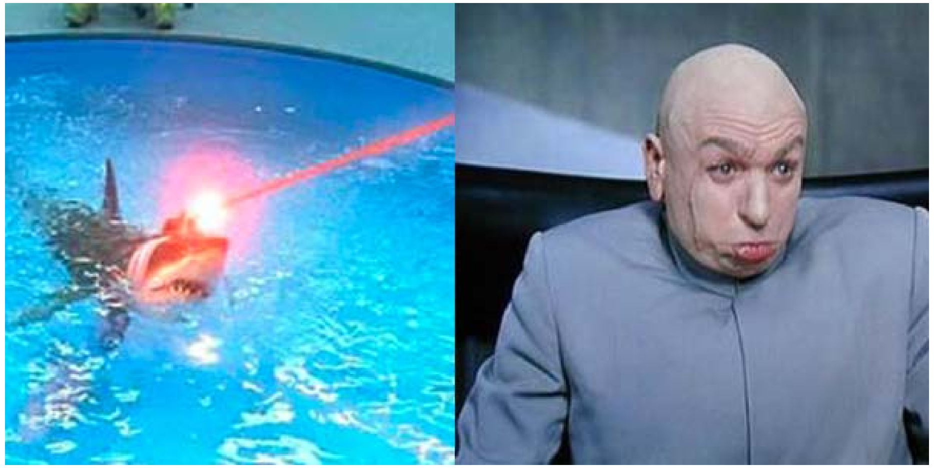
No modification to laser

- Minimizing divergence
- Increased irradiance

Unmanned Aerial Systems: aka drones

- Mounted lasers

Future threats?



Critical Phases of Flight

Final approach and take off

- The closer the ground, the greater propensity for eye injury
- The real threat is distraction: potential for missed approaches or worse
- No aircraft mishap to date secondary to laser exposure*

Take Home Message

Retinal damage is impossible for aircrew

Cornea damage is impossible

Reassurance is key

Aircrew may follow up during regular clinic hours

Thank you!

Questions???

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