Simulating Aircrew Laser Dazzle in a Virtual Reality Environment

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ABSTRACT

According to the U.S. Federal Aviation Administration (FAA) and other sources, lasing of aircraft is a growing aviation safety concern nationwide, with 12,840 aircraft illumination events reported to the FAA in 2024. Though there have been isolated reports of pilots sustaining eye injuries that cause persisting visual impairment, the primary risk associated with laser strikes is pilot distraction from temporary effects such as dazzle (i.e. glare) and afterimages during a critical phase of flight. In an effort to support the introduction of a laser experience into pilot training programs, we have created a simulation of laser dazzle effects in virtual reality (VR), to include dazzle and afterimages. While the luminance of a typical digital display cannot match that of a high-brightness laser, the apparent visual contrast reduction resulting from laser glare can be simulated on a display to be empirically accurate for given quantitative parameters of the visual scene and laser being simulated. The extent of the visual field obscured by the VR laser dazzle effect was measured in a small group of human participants. The results generally correlated well ($r^2 > 0.95$) with empirically-based model predictions of obscuration angle under the same irradiance and background luminance conditions, though the measured angles were smaller than the predictions, suggesting implementation improvements for future work. To safely demonstrate the laser strike experience or allow for pilots to learn countermeasures, this dazzle package could be incorporated into the virtual reality training applications that are being increasingly used in pilot. The overall goal of this effort is to create validated laser dazzle packages that can be incorporated into VR flight simulators to enable wargaming, training, education, and development of tactics in response to laser exposures, these being difficult or impractical to accomplish with physical lasers and live training.

ABOUT THE AUTHORS

Mr. Sonny Ponce is a game developer at SAIC specializing in Unity applications for both virtual reality and desktop applications. He is responsible for the planning, managing, and execution of game development applications used in human vision and perception research. His portfolio includes the development of a virtual visible wavelength laser as viewed by a pilot from the cockpit in a virtual reality simulation as well as a virtual color vision test system. He received his BS degree in Animation and Game Design from the University of the Incarnate Word.

Dr. Joseph Arizpe is a vision and data scientist working on SAIC's Vision Science and Eye Protection team and supporting Air Force Research Laboratory's (AFRL) directed energy bioeffects research at Fort Sam Houston, Texas. He conducts visual perception research to inform modeling and simulation efforts within AFRL. He holds a PhD in Cognitive Neuroscience obtained from the University College London (UCL) and National Institutes of Health (NIH) joint PhD program, and holds a BS in Cognitive Science from Carnegie Mellon University.

Mr. Jake McKenna is a game developer formerly working for SAIC to design and develop a scientifically accurate laser glare simulation and virtual reality software for vision research in the Unity game engine. He holds a BS in Game Design and Production from Drexel University.

Dr. Peter Smith leads SAIC's Vision Science and Eye Protection team, which supports the Air Force Research Laboratory's directed energy bioeffects research at Fort Sam Houston, Texas. A leading expert in laser bioeffects on the eye and visual system, his research has directly informed models for predicting transient visual effects and developing advanced laser eye protection. Dr. Smith's work is pivotal in assessing warfighter vulnerability, defining

protection standards, and developing non-lethal optical systems. He holds a PhD in Medicine, an MS in Biophysics and Bioengineering, and a BS in Biological Sciences, all from universities in the United Kingdom.

Mr. Christian Calimlim is an operations research analyst serving as a government principal investigator for the Air Force Research Laboratory's directed energy bioeffects modeling, simulation, and analysis team. He is responsible for acquiring, applying, and managing bioeffects products for mission-level and engagement-level modeling. He holds a M.Eng. in Chemical and Biological Engineering from Princeton University and a B.S.E. in Biomedical Engineering from Tulane University.

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INTRODUCTION

The human eye is susceptible to two main effects from laser radiation: damage and dazzle. Damage is possible when the eye is exposed to enough laser energy to cause lesions or burns, which can result in partial blindness. Visible wavelength lasers can also induce non-damaging eye effects, such as disability glare and veiling glare (collectively referred to as laser dazzle) that can partially obscure the visual field and increase the time to recognize and respond to operationally relevant visual information. Transient scotomas, or temporary flash blindness, can also occur. The use of dazzle lasers as a non-lethal optical countermeasure is well-established in military scenarios, where they are used to warn individuals or temporarily disrupt the vision of adversaries (Joint Non-Lethal Weapons Program, 2016; Shannon, 2013; Titterton, 2004, 2010).

Currently, laser safety standards provide comprehensive guidance for managing the risks of eye damage associated with exposure to laser sources (American National Standards Institute, 2022). Guidance also exists for protecting general aviation pilots against non-damaging eye effects of lasers (American National Standards Institute, 2015). Laser strikes refer to the intentional and hazardous illumination of aircraft, vehicles, or other targets with a laser beam, usually by individuals on the ground. This reckless behavior poses a significant threat to aviation safety, especially during critical phases of flight such as takeoff or landing.

The FAA handled 12,840 reports of laser strike incidents against commercial aircraft in 2024 (Federal Aviation Adminstration, 2025). Similar incidents have been reported in military environments (Lubold, 2018). The number of domestic incidents represents a significant increase from prior years. In most cases, laser strikes are perpetrated by individuals with handheld laser pointers, often with malicious intent or as a prank, but without realizing the serious consequences of their actions. Law enforcement agencies and aviation authorities take these incidents seriously, and offenders can face severe penalties, including fines and imprisonment, for their irresponsible behavior (Fortonska & Debowski, 2023). The rising frequency of laser strikes has led to the advancement of laser eye protection (LEP) for commercial and police helicopter pilots (Newton et al., 2023).

Since LEP may not be widely available, approaches to mitigate the threat of laser dazzle include training personnel who may be exposed to laser threats. This ensures that when these persons encounter a laser strike unexpectedly, they are better prepared for it and can carry out appropriate defensive actions. However, training with real laser exposures is difficult to implement as special care must be taken when planning and setting up the laser to ensure safety, and the permission of an ethics committee may be needed, which may involve a long lead time and increased cost.

An alternative for live training is a validated laser dazzle simulation which could also be valuable for research on the impact of laser dazzle on human performance within military operating environments. For studies involving scenarios for which real-world experiments would be unsafe or logistically impractical, controlled experiments utilizing simulations of laser dazzle in immersive virtual environments would be highly advantageous.

Several groups have attempted to provide such training using simulated dazzle. Williamson (2016) demonstrated a simple technique for superimposing a dazzle field onto scene imagery to provide a visualization of dazzle severity in a given scenario, compressing the luminance range to the instantaneous range of human vision. An extension of this approach included the effects of LEP (Freeman & Williamson, 2020). Henrichsen et al. (2021) extended the visualization concept to an augmented reality (AR) environment, and compared the extent of the simulated dazzle field measured in human participants with predictions based on the dazzle model developed by Williamson et al. (2017). They made measurements at background luminance levels of 0.9 cd/m^2 and 13.0 cd/m^2 and found that the dazzle extent in the simulation was slightly higher than model predictions. The differences were attributed to limitations in presenting the real peak brightness of the laser dazzle.

One limitation of using an AR technology for the laser presentation is that the magnitude of the dazzle effect is dependent upon the ratio of the dazzle brightness to the background light brightness. As the background light brightness is increased, the AR display, having a maximum luminance on the order of 500 cd/m^2 reaches its limit, and the dazzle effect cannot be scaled to daytime luminance levels, rendering it is less effective than it should be.

Our aim is to develop a dazzle simulation in a virtual reality (VR) environment, where it should be possible to simulate the effects of dazzle at daytime luminance levels by compressing the luminance range to within the dynamic range of the VR display. To this end, we have developed and validated a Unity® game engine laser dazzle simulation package that replicates the visual disturbances, specifically the contrast reduction, experienced during laser exposure. Known technical limitations of currently available VR headset displays makes it necessary to make target contrast adjustments to compensate for the headset's inability to replicate high irradiance and high background luminance levels. The simulation aims to facilitate wargaming, training, education, and development of strategies to counteract laser exposure in a safe, controlled environment, circumventing the hazards and limitations associated with the use of actual lasers in live training scenarios. This paper provides details on the implementation within a Unity® shader of the simulation structure and details the validation of our simulated glare effect as compared to that of actual laser dazzle.

BACKGROUND

Our laboratory has carried out a number of studies investigating the factors affecting the extent of laser eye dazzle experienced by human observers (McLin et al., 2013; Williamson et al., 2018, 2017). From these, we developed a theoretical model of laser eye dazzle (Williamson et al., 2017). This model takes into account the relevant contributing factors with input parameters to define the laser (irradiance, beam divergence, and wavelength), the viewing conditions (ambient light level), the observer characteristics (age, eye color), and the task being performed (size and contrast of the object being viewed).

The foundation of the model is the Commission Internationale de l'Eclairage (CIE) general disability glare equation that describes light scatter within the human eye (Vos et al., 2002). This equation quantifies the eye's susceptibility to glare depending on the illumination at the eye. The CIE developed this equation for broadband, non-laser light sources based on experiments at low ambient light levels of <100 cd/m^2. Our research adjusted the CIE broadband model to improve its accuracy at predicting laser dazzle effects at higher background luminance levels.

Like Henrichsen et al. (2021), we used the Williamson et al. (2017) model as a basis for the development of our simulation of eye dazzle. However, to compensate for the limited dynamic range of VR headsets, and represent the extent of dazzle across the visual field, we made adjustments to the target contrast by spatially modulating the transparency (i.e., alpha) values of an overlay representing laser glare. By carefully adjusting the contrast of the virtual scene, the perceived severity of the dazzle effect can be made to more closely match the expected real-world experience. This adjustment will help to improve the realism and accuracy of the VR simulation and ensure that the wargaming, training, educational or experimental objectives are met (Figure 1).

Figure 1. Laser Dazzle Simulation

Evaluating the effects of these contrast adjustments in the context of validating the accuracy of the VR laser dazzle simulation is essential. This validation can be achieved by comparing the extent of the visual field obscured by the simulated dazzle effect with the model predictions obtained under similar irradiance and background luminance conditions. A close correlation between the VR simulation and the dazzle model increases confidence in the simulation and its effectiveness as a training and research tool.

METHODS

Laser Dazzle Effects Overview

The CIE general disability glare equation (Vos et al., 2002) predicts the distribution of veiling luminance on the retina. A modified equation from (Williamson et al., 2017) adjusts the light distribution to account for changes that occur in high ambient luminance conditions. These equations model intraocular scatter to provide a veiling luminance for a given angle between the light source and a point in the observer's field of view. Other nuanced components of intraocular glare such as the ciliary corona and lenticular halo have been characterized by Ritschel et al. (2009), and we have also incorporated these into our simulation.

Additionally, many viewers report a rough textural quality to laser glare, that can appear as "noise," "bumps," or "waves". This is thought to be caused by constructive and destructive interference of laser light that arrives in different phase shifts at the retina, manifesting perceptually as bright and dark spots, often referred to as speckle. We approximate the perceptual experience of speckle with common Perlin noise (Bennett, 2019). Perlin noise is a gradient-based procedural noise function used to simulate various natural phenomena and create realistic textures in digital content.

Pupillary fluctuations are another subtle effect that occurs as the eye modulates incoming light by changing the size of the pupil, causing temporal fluctuations in the glare field. In our simulation, we use a fluctuation modeled from Ritschel et al. (2009). The simulated effect aligns well with our own perceptual experiences of laser glare.

Scintillation is a significant factor in the appearance of laser glare. Scintillation refers to random fluctuations in the irradiance of the beam due to atmospheric turbulence. We simulated scintillation with a Perlin noise function capped at a 5% influence. Capping the influence of the function preserved the accuracy of the contrast reduction in the laser simulation.

Laser Beam Propagation

The dazzle extent is determined by the irradiance at the eye, and the irradiance at the eye is determined by beam propagation. The beam propagation in our simulation takes into account the laser power, the beam diameter at the laser source, and the divergence of the beam to determine the irradiance at the eye. Greater divergence leads to a lower irradiance at the eye. The irradiance may also be reduced by other factors such as absorption, scattering and diffraction in the atmosphere, though these are not modeled currently in our simulation. We model beam propagation with a virtual beam to determine the irradiance level to render for our dazzle overlay. Our beam propagation system consists of components described in more detail next.

We incorporate a `Tracking` component that controls how the laser is tracking the observer and an `LEP Controller` component that stores information for simulated LEP being used by the observer. The `Laser Simulation Manager` controls the laser simulation as a whole. It initializes the `Laser Controller` and `Observer` components. After initializing these components, the processing then begins with the `Laser Controller` component. The `Laser Controller` component checks if the observer is within the "cone" of the laser propagation and, using a simple raycast, checks that no objects are blocking the laser. When both are true, a laser hit struct is created and passed to the `Observer` component to be processed.

In the `Observer` component, aspects of the observer's condition are also factored into the rendering process. The `Observer` class contains information on the ambient lighting conditions at the point of observation, the position, direction, age, and eye color of the observer, and the transmittance of the LEP. This information is passed to the Laser Hit Handler components within the scene. There are two Laser Hit Handlers: the `Canvas Controller` and the `Dazzle Controller`.

The `Canvas Controller` class handles the positioning of a screen-space canvas that holds the main quad object on which the laser simulation is rendered. The canvas is placed in the scene at the laser source and the `Canvas Controller` keeps the quad oriented towards the observer camera and dynamically scales it by calculating and setting the plane distance of the canvas. We do this to avoid a "double-vision" effect of the laser source in binocular VR displays.

The `Dazzle Controller` class formats and passes all necessary information to the Dazzle Shader. It contains property variables that the Dazzle Shader uses to render the laser dynamically each frame. These variables are updated only on a state change to limit the writing of variables to the shader to only once per frame. The properties passed to

each frame through the LaserHit struct are the observer's position, age, and eye pigmentation, the ambient luminance, the position of the laser origin, and the laser irradiance given the laser power and beam divergence at the observer's position (and the LEP filtration, if applicable).

The laser irradiance, I, is calculated using:

$$I = \frac{\text{laser power}}{\pi r^2}$$

where r is the radius of the laser beam at the observer's position, as calculated by our beam propagation system.

The `Dazzle Controller` class also contains the photopic luminous efficiency function, which will aid in the veiling luminance calculation that comes later:

$$V(\lambda) = \exp\left(-\frac{1}{2}\left(\frac{\lambda - 559}{41.9}\right)^2\right)$$

where:

- $V(\lambda)$ is the photopic luminous efficiency approximation at wavelength λ (in nanometers)
- λ is the wavelength of light (in nm)
- 559 is the center wavelength where the function peaks
- 41.9 is the standard deviation, determining the width of the Gaussian distribution.

The `Dazzle Controller` class also calculates the linear RGB color of a given laser wavelength, λ in nanometers (nm), to be used later in the Dazzle Shader:

$$R(\lambda) = \begin{cases} 0, & 380 \leq \lambda < 510 \\ \frac{\lambda - 510}{70}, & 510 \leq \lambda < 580 \\ 1, & 580 \leq \lambda < 780 \\ 0, & \text{otherwise} \end{cases}$$

$$G(\lambda) = \begin{cases} 0, & 380 \leq \lambda < 440 \\ \frac{\lambda - 440}{50}, & 440 \leq \lambda < 490 \\ 1, & 490 \leq \lambda < 580 \\ 1 - \frac{\lambda - 645}{65}, & 580 \leq \lambda < 645 \\ 0, & 645 \leq \lambda \leq 780 \\ 0, & \text{otherwise} \end{cases}$$

$$B(\lambda) = \begin{cases} 1, & 380 \leq \lambda < 490 \\ 1 - \frac{\lambda - 510}{20}, & 490 \leq \lambda < 510 \\ 0, & 510 \leq \lambda < 780 \\ 0, & \text{otherwise} \end{cases}$$
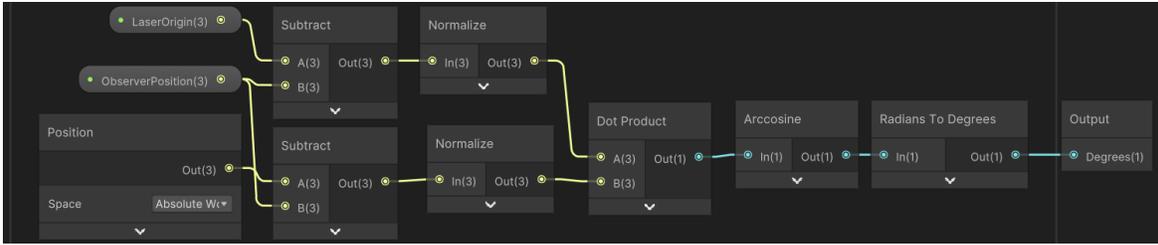
The Dazzle Shader

A shader is a program used in computer graphics to perform operations during the rendering process. These programs execute on the Graphics Processing Unit (GPU), leveraging the highly parallelized nature of graphics processing. Shaders can operate in different contexts including vertex, fragment, or compute. Our dazzle simulation uses a High Definition Render Pipeline (HDRP) fragment shader in Unity® set to a linear color space workflow. A fragment is a screen-space sample of a virtual surface relative to a pixel. Fragments can be thought of as a collection of samples that contribute to the final color of a pixel. A pixel can have many fragments included in its final color, or just one.

After the propagation and variable translations are complete, all data is passed to the Dazzle shader. Using the Unity® Shader Graph tool, the shader is divided into six subsections through the use of Shader subgraphs. These subgraphs are Angle Calculation, Veiling Luminance Calculation, Color Mapping, Alpha Derivation, Scintillation/Noise, and Pupil Fluctuation. Following are details of the flow of the graph.
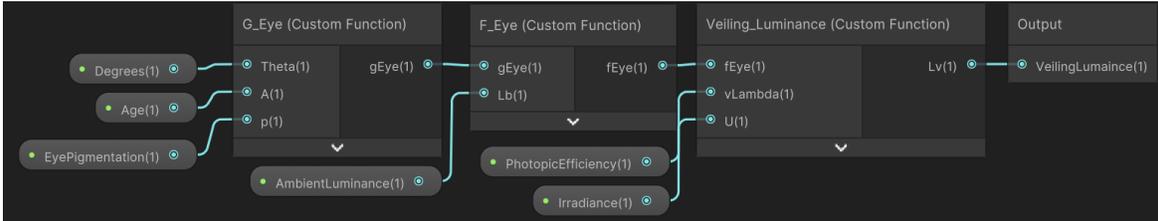
The Angle Calculation subgraph (Figure 2a) calculates the angle between the center of the dazzle source in the visual field and the current shader fragment that is being rendered. This angle is used in the Veiling Luminance Calculation subgraph. We calculate the visual angle using the laser origin and observer position information from the beam propagation calculation and using the built-in shader function of absolute world position. This visual angle corresponds to the current fragment's radial distance from the center of the dazzle source.

The Veiling Luminance Calculation subgraph (Figure 2b) calculates the veiling luminance given the visual angle relative to the laser source, the observer age and eye pigmentation, the ambient luminance, the photopic efficiency of the eye, and the laser irradiance at the eye. This is an implementation of equations 1, 2, and 3 in Williamson, 2016, and models the intraocular scatter of the laser onto the retina. These equations were implemented as three custom functions inside of the shader graph. The final output of these calculations is an equivalent veiling luminance in cd/m^2 for the fragment at the given visual angle.
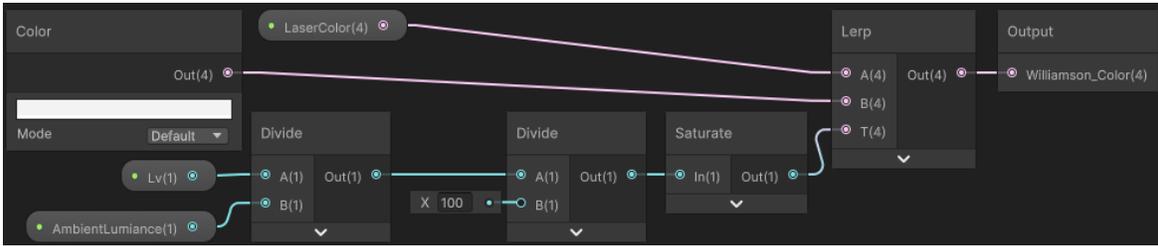
The Color Mapping subgraph (Figure 2c) produces a gradient of color ranging from white to the perceptual color associated with the wavelength of the laser (e.g., green for 532 nm lasers). The basis for this color gradient comes
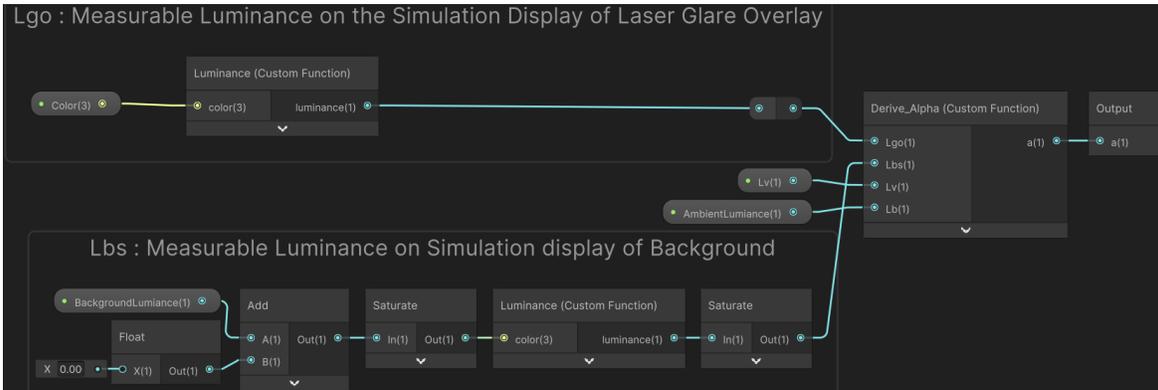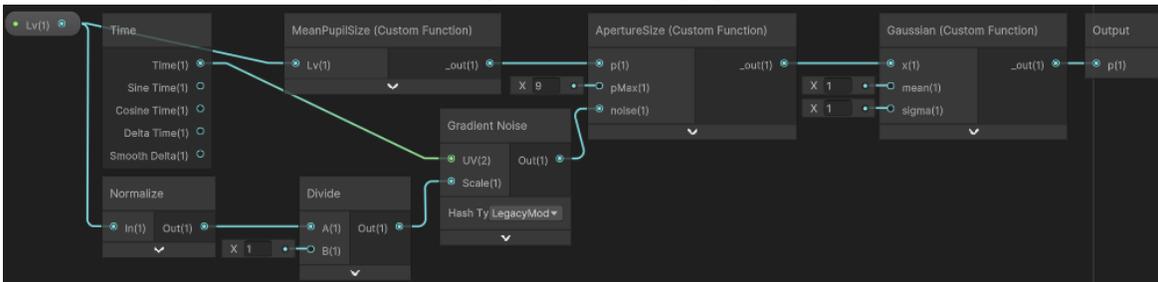
(a) Angle Calculation subgraph

(b) Veiling Luminance Calculation subgraph

(c) Color Mapping subgraph

(d) Alpha Derivation subgraph

(e) Pupil Fluctuation subgraph

Figure 2. Dazzle Shader Graph

from Williamson, 2016, which assumes a dynamic range ratio for luminance perception of approximately 100:1, in accord with the known dynamic range of cone photopigments. This means that when the luminance of the laser glare is less than 1/100th of the background or ambient luminance, the veiling luminance of the laser should be imperceptible. Beyond 100× the background or ambient luminance, the veiling luminance should fully obscure perception of the background. The color gradient begins from purely the color of the laser when the ratio is $1/100^{th}$ or less, but once the 100× ratio is exceeded, the color becomes white to simulate saturation of retinal pigments. For the intervening ratios, the color is linearly interpolated. The resulting appearance aligns well with the authors' subjective perceptual experience of laser glare such that the center of a bright laser source appears white and the rest of the scattered laser light appears colored.

The contrast reduction simulating veiling laser glare is accomplished by modulating the alpha (i.e., transparency) values of the glare overlay fragments in the shader. Full details of the mathematical and vision science basis for this alpha modulation method to be accurate for given parameters of the visual scene and the laser being simulated are found in Hart et al., 2023. The Alpha Derivation subgraph (Figure 2d) implements equation 13 from Hart et al., 2023, which determines the alpha level to be set at the given shader fragment, assuming the display luminance of the color of the glare overlay fragment (from the Color Mapping subgraph), the display luminance of the designated background, and the nominal background and veiling luminances being simulated. Assuming the sRGB color standard, the display luminances do not need to be measured directly from the screen, but can be derived with equations 8 and 9 in Hart et al., 2023. Those equations are implemented in custom functions within the Alpha Derivation subgraph.

The Scintillation/Noise subgraph is a simple Perlin noise function, called Gradient Noise, with a random range of 0 to 1. If scintillation is off, the Perlin noise is used to simulate the spatial variations in retinal intensity of the laser exposure. When scintillation is active, the Perlin noise modulates the alpha of the glare overlay temporally to mimic the fluctuation in the irradiance of the beam due to atmospheric turbulence. We cap this effect at a value of 5% to avoid excessive increases or decreases in the overall opacity of the laser glare overlay beyond the targeted level, while still adding to the fidelity of the simulation.

The Pupil Fluctuation subgraph (Figure 2e) simulates the pupillary dilations and contractions that naturally occur in the human eye and adds a minor "pulsation" effect to the glare. In this subgraph, we implemented equations 1 and 2 from Ritschel et al. (2009) and then applied a Gaussian function. The resulting output is then added to the output of the Scintillation/Noise subgraph which is subjected to the 5% influence rule.

Validation Study

To test the accuracy of our VR implementation of laser dazzle, we performed a study (AFRL IRB protocol FWR20230100H) in the VR environment that replicated the methodology of prior dazzle studies with real lasers (Smith et al., 2024; Williamson et al., 2018, 2017). The aim was to measure contrast thresholds during simulated laser dazzle exposures for a variety of scenarios and compare the results with dazzle model predictions. Since the dazzle model does not predict the contrast threshold, but rather the obscuration angle, we used the dazzle model to predict the obscuration angle for a target presented at the measured contrast threshold under the same laser and background exposure conditions, and then compared that angle with the actual measurement angle in VR.

The study used an HP Reverb G2 Omnicept VR headset, which had a maximum display luminance of around 150 cd/m^2. We employed a simple letter orientation task utilizing a Landolt C, where a "C" character was presented at different eccentricities from the laser source, and the contrast of the C was varied by changing the letter luminance. The size of the gap in the Landolt C was 16.9 min of arc, corresponding to a Snellen acuity of 20/337. The participant looked directly at the letter and attempted to determine the orientation of the gap, which could be one of four choices; down, left, up, or right (Figure 3a).
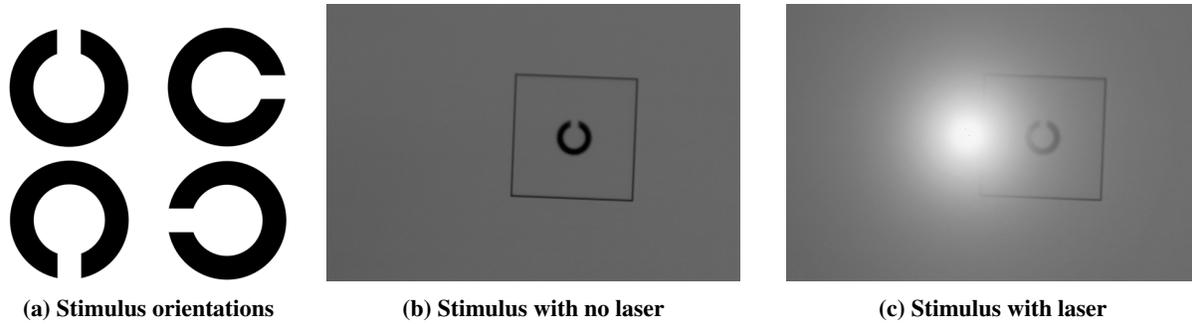
(a) Stimulus orientations **(b) Stimulus with no laser** **(c) Stimulus with laser**

Figure 3. Landolt C stimuli

Contrast thresholds were established using an adaptive threshold technique (Prins, 2013) with thirty stimuli being presented. The independent variables used in the study (ambient luminance, eccentricity angle, and laser irradiance) are shown in Table 1. These conditions were selected based upon the authors' previous experience (Smith et al., 2024), and the results of pilot experiments we performed. The laser irradiance levels were chosen to produce elevated contrast thresholds at each combination of ambient luminance and measurement angle. The irradiance needed for this increased with ambient luminance and decreased with measurement angle.

Each participant's age and eye color were used to calculate their individualized glare profile for the laser simulation. A Participant's view of a high contrast stimulus with no laser, and with a typical laser simulation are shown in Figure 3b and Figure 3c, respectively. The adaptive threshold algorithm varied the luminance, and hence contrast, of the stimulus until the participant's correct responses are at a level that is just above chance.

Thresholds in terms of Weber contrast values for each combination of the conditions in Table 1 (luminance angle $\times$ irradiance) were measured in sixteen participants with an average age of 37.5 ± 14.6 (s.d.) years, according to a balanced random order design. Table 2 shows the measured contrast thresholds averaged across all participants. Our previous work on laser dazzle showed that contrast thresholds increase with increasing laser irradiance, decrease as the ambient luminance increases, and decrease as the angle between the laser and the target (eccentricity) increases (Smith, 2007; Smith et al., 2024; Williamson et al., 2017). The same trends are seen in the data in Table 2.

We then used the experimental variables (participant age and eye pigment, laser irradiance, ambient luminance) and the measured contrast thresholds as input values for our dazzle model (Williamson et al., 2017) to predict the obscuration angle for those parameters, which should correspond to the measured angle. We then compared

Table 1. Study Variables - Laser Irradiance for each Ambient Luminance $\times$ Measurement Angle combination (μW/cm^2)

Ambient Luminance (cd/m^2)	Measurement Angle (°)			
	3	6	12	24
6	1	1	-	-
	4	4	4	-
	-	16	16	16
100	4	4	-	-
	16	16	-	-
	-	64	64	-
	-	256	256	256
	-	-	-	600
1,000	16	-	-	-
	64	64	-	-
	-	256	256	256
	-	600	600	600

Table 2. Contrast Threshold Results (means of 16 participants)

Ambient Luminance (cd/m^2)	Laser Irradiance (μW/cm^2)	Measurement Angle (°)			
		3	6	12	24
6	1	5.1	2.8	-	-
	4	16.6	4.3	2.6	-
	16	-	13.6	3.6	2.4
	64	-	-	-	4.4
100	4	3.2	-	-	-
	16	7.0	3.2	-	-
	64	-	7.0	3.2	-
	256	-	39.4	7.3	3.1
	600	-	-	-	4.8
1,000	16	2.1	-	-	-
	64	3.8	2.2	-	-
	256	-	3.5	2.5	1.8
	600	-	8.6	3.0	2.5

the predicted angle with the angle used for each measurement. The results of this comparison are shown in Figure 4, where the measurement angle for each ambient luminance level is plotted against the predicted obscuration angle. For this comparison, since the shader is based on the dazzle model, ideal agreement would be when the measured angles are equal to the model predictions. Generally, the measured angles correlate well with the predictions ($r^2 > 0.95$), but while the overall correlation is strong, the measured values consistently fall below the predicted values. The reason for this is not immediately apparent, but the most likely cause is that the shader is not reducing the scene contrast enough. A simple experiment could be used to test the effect of adjustments to the shader parameters and bring the simulation closer to the model predictions.
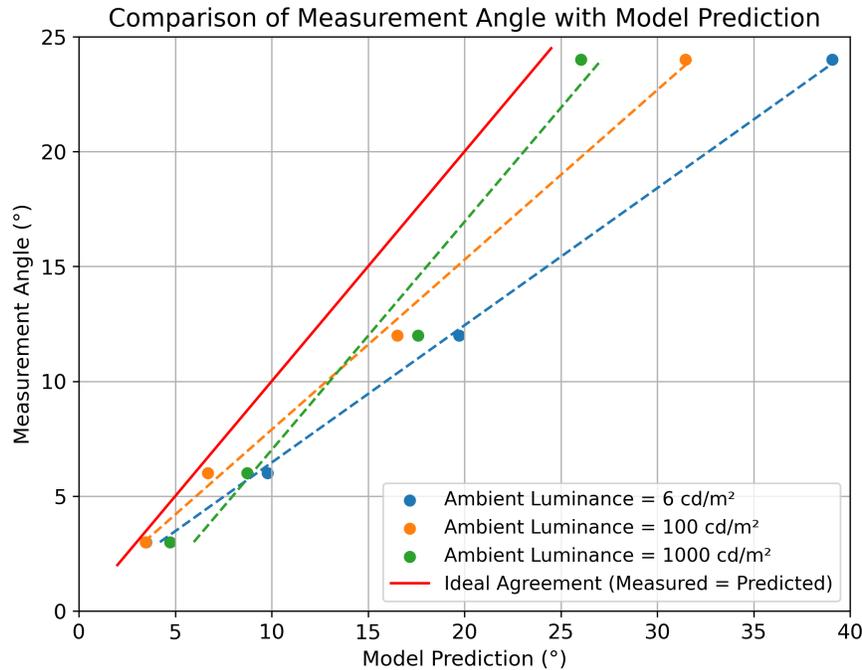

Figure 4. Comparison of measurement angles with predicted obscuration angles (mean of 15 participants)

SUMMARY

The increasing prevalence of laser strikes on aircraft has become a significant concern for aviation safety. To address this we developed a VR simulation that replicates the effects of laser dazzle on the human eye. While current VR displays cannot achieve the same luminance levels as high-powered lasers, the simulation effectively reproduces the apparent visual contrast reduction that occurs with laser glare. The simulation incorporates key components of laser dazzle, including disability glare, veiling glare, transient scotomas, and afterimages.

To validate the accuracy of the VR simulation, we conducted a study with human participants, measuring the extent of the visual field obscured by the simulated dazzle effect. The results of the study showed a strong correlation between the obscuration angles measured in the VR environment and the obscuration angles predicted by an empirically-based model. While some adjustments to the dazzle field are needed to improve the correlation with real-world data, this validation confirms that the VR simulation can reliably replicate the visual effects of laser dazzle.

The development of this validated laser dazzle simulation in VR offers a valuable tool for wargaming, training, education, and the development of effective countermeasures to laser exposure. It provides a safe, controlled, and repeatable environment for such activities, overcoming the cost, limitations and hazards associated with using actual lasers in live training scenarios.

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