МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
ФАКУЛЬТЕТ АЕРОНАВІГАЦІЇ, ЕЛЕКТРОНІКИ ТА ТЕЛЕКОМУНІКАЦІЙ
КАФЕДРА АВІОНІКИ

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач випускової кафедри
_________С.В. Павлова
«___»___________2022

ДИПЛОМНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ
БАКАЛАВР ЗА СПЕЦІАЛЬНІСТЮ 173
«АВІОНІКА»

Тема: «Захист пілотів від засліплення на етапах злету та посадки»

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MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
FACULTY OF AIR NAVIGATION, ELECTRONICS, AND TELECOMMUNICATIONS

DEPARTMENT OF AVIONICS

APPROVED
Head of department
________S.V. Pavlova
'___'___________2022

GRADUATION WORK

(EXPLANATORY NOTES)

FOR THE DEGREE OF BACHELOR
SPECIALTY 173 'AVIONICS'

Theme: 'Anti-dazzle protection for pilots during take-off and landing'

Done by: __________ (signature) Y.Y. Yakovlev

Supervisor: __________ (signature) S.V. Pavlova

Standard controller: __________ (signature) V.V. Levkivskyi

Kyiv 2022

NATIONAL AVIATION UNIVERSITY

Faculty of Air Navigation, Electronics and Telecommunications

Department of avionics

Specialty 173 ‘Avionics’

APPROVED

Head of department

_________S.V. Pavlova

‘___’___________2022

TASK for execution graduation work

Y.Y. Yakovlev

1. Theme: ‘Anti-dazzle protection for pilots during take-off and landing’, approved by order №352/ст of the Rector of the National Aviation University of 04 April 2022.
2. Duration of which is from 16.05.2022 to 19.06.2022.

3. Input data of graduation work: Modern methods of preventing blinding of pilots at the stages of takeoff and landing. Experimental inventions that can solve the problem of blindness. Military technology that can be used for civil aviation.

4. Content of explanatory notes: Analytical review of literature sources from diploma topics. Identification of physiological preconditions leading to the dazzle. Research of aviation accidents caused by dazzling of pilots. Research of methods of prevention of the dazzle in modern aviation. Search for promising methods to prevent the dazzle.

5. The list of mandatory graphic material: figures, charts, graphs.

6. Planned schedule

№	Task	Duration	Signature of supervisor
1.	Validate the rationale of graduation work theme	16.05-20.05	
2.	Carry out a literature review	21.05-24.05	
3.	Develop the first chapter of diploma	25.05-01.05	
4.	Develop the second chapter of diploma	02.05-06.06	
5.	Develop the third chapter of diploma	07.06-12.06	
6.	Tested for anti-plagiarism and obtaining a review of the diploma	13.06-19.06	

7. Date of assignment: May 16 2022 year

Supervisor ________________ S.V. Pavlova

(signature) (surname, name, patronymic)

The task took to perform ________________ Y.Y. Yakovlev

(signature) (surname, name, patronymic)

ABSTRACT

The explanatory notes to the graduate work 'Anti-dazzle protection for pilots during take-off and landing' contained 52 pages, 7 drawings, 2 tables, 4 flow-charts, 13 reference books

Keywords: DAZZLE, EYES PROTECT, LASER, SUN GLARE, ACCIDENTS, OPTICS, TAKEOFF, LANDONG, PILOT.

The object of the research: process of dazzle of pilots during take off and landing.

The subject of the research: modern and promising methods of combating the dazzle.

The purpose of the graduate work: to analyze existing methods anti-dazzle protection for pilots during take-off and landing

Research methods: comparative analysis, literary processing sources, research method.

Thesis plan

On the topic: “Anti dazzle protection for pilots during take-off and landing”

Abbreviation

FAA-Federal Aviation Administration

TSB-Transportation Safety Board

GPS- Global Positioning System

FDA-Food and Drug Administration

SAE-Society of Automotive Engineers

FSEL-Flight Safe Exposure Limit

MPE-Maximum permissible exposure

NFZ-Normal Flight Area

SFZ-Sensitive Flight Zone

LFZ-Laser Free Zone

AGL-Above ground level

NM-nautical miles

CFZ-Critical Flight Zone

UV- ultra violet

AMAS-Aviation Medical Advisory Service

SRC-scratch-resistant coating

OD-optical density

VLT- visual light transmission

FAR-Federal Aviation Regulations

FCOM-Flight Crew Operation Manual

QRH-Quick Reference Handbook

HUD-Head Up Display

LEP-Laser eye protection

AR-anti-glare

LEP-Laser eye protection

Introduction

Relevance of the graduate work: The problem of dazzle of pilots in the sun during the takeoff and landing stages has always been acute for aviation engineers. Dazzle is dangerous because it leads to loss of orientation in the space of the pilot, which in turn leads to loss of control of the aircraft. It can also lead to eye injuries. From the very beginning of the invention of the aircraft, the search for methods to solve this problem began. Sun dazzle of pilots is especially an acute problem for airports that are located near water or where there is snow. Also, the number of cases where pilots have been deliberately dazzle by laser attackers has also increased recently. The main reason for this is that today lasers with sufficient power are a common commodity. This problem is quite new, and therefore there is no final solution today.

That is why the main purpose of this thesis is to overcome all the above problems and increase the safety of landing and takeoff.

The object of the research: process of dazzle of pilots during take off and landing.

The subject of the research: modern and promising methods of combating the dazzle.

The purpose of the graduate work: to analyze existing methods of anti-dazzle protection for pilots during take-off and landing.

1. Physiological prerequisites and cases of dazzle

1.1Physiological features of the eye that lead to dazzle

The human eye is a complex biological mechanism. It allows us to distinguish colors, correctly determine the distance to objects, to adapt to different levels of lighting. These qualities directly affect the ability of pilots to operate the aircraft. However, the human eye is not perfect, and some of its shortcomings affect the pilot during takeoff and landing. In my case, I will consider such a negative phenomenon as dazzle.

The first thing I would like to start with is to define the dazzle. **Dazzle (or glare)** refers to the temporary inability to see details in the area of the visual field around a bright light (such as an oncoming car's headlights). Dazzle is not associated with biological damage. It lasts only as long as the bright light is actually present within the individual's field of vision. It doesn't matter if the light comes from a laser, flash or ordinary light source, such as the sun or a searchlight. Laser glare can be more intense than solar glare. But also, in dark surroundings, low levels of laser light may already cause inconvenient glare. Dazzle that impairs vision is called disability glare. Light induced visual disturbances are the result of neural processing in the retina or in areas upstream the visual cortex, and thus occur only after light has been absorbed by the photoreceptors (Figure 1.1.1). [1]

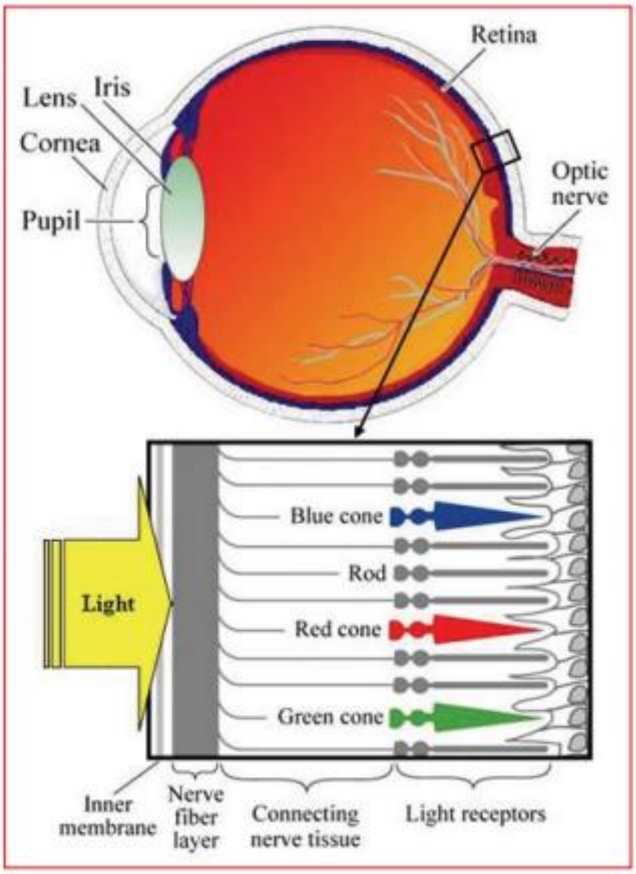


Figure 1.1.1 Diagram of the human eye

The sudden appearance of a flash of light inherently attracts visual attention and distracts someone from his true task. The secondary effect may be disorientation or panic. But with the help of training, these effects can be reduced. Also, the negative effects of these effects are more pronounced in the elderly, in tired people, in people with mental illness (depression, bipolar disorder, etc.), in people who are in a state of alcohol or drug intoxication. [2]

One of the factors that affects the possibility of dazzle of pilots is the time of day. At sunset or sunrise, the sun is near the horizon, and therefore at eye level. As a result, light without reflections can enter the eye freely and the possibility of dazzle increases several times. Also during night flights there is a high possibility of dazzle. When the eyes are adapted to low light, exposure to light (brightness that does not exceed normal daylight) can lead to temporary visual impairment, blindness and residual images.

The following are recommendations from the Civil Aerospace Medical Institute for optimizing visual performance and improving aviation safety during night operations. Federal Aviation Administration:

- Thoroughly clean the windshield during the pre-flight test. It should also be regularly inspected for damage, which can lead to glare from increased light scattering. If there is damage to your windshield, it must be replaced.
- You need to allow your eyes to properly adapt to the darkness by wearing sunglasses during the day, and avoid bright lighting before flying at night.
- If possible, avoid medications that can affect the eyes' sensitivity to light or prolong recovery after exposure to a bright light source. These include some over-the-counter non-steroidal anti-inflammatory drugs and prescription drugs such as antibiotics, oral contraceptives and acne medications.
- Keep one eye closed if you are looking in the direction of a bright light source to maintain adaptation to darkness in at least one eye. Use a glare canopy (sun visor) or other opaque items to protect your eyes from the harsh light of the ramp.
- Keep in mind that some forms of ophthalmic correction or refractive surgery may increase the sensitivity to glare, so if you are a pilot, you should consult with your doctor whether such a surgical procedure would be appropriate.

Inform the relevant airport authorities of any damaged, inefficient or inappropriate airport navigation aids and lighting problems both inside and outside the airport, as well as the use of lasers near the airport.

- To prevent the flash from blinding other pilots, dim the landing lights as soon as safety concerns allow.
- After determining the runway, if possible, dim the approach lights to avoid glare and to ensure that adaptation to darkness during deployment and taxiing is not disturbed.
- Be prepared for the fact that external lighting is reflected back into the cabin during the flight in minor weather conditions, such as fog, fog, rain or snow.
- Use off-axis vision and peripheral visual cues to help estimate altitude and distance when glare is present.
- Maintain extreme lighting conditions in the cab to preserve some cone photopigment function and avoid night myopia.

Another factor that affects the possibility of dazzle the pilots is the level of reflection of sunlight from the surface around the airports (runways). If the airport is located near a body of water or in snowy areas, the possibility of dazzle of pilots will be greater than in other areas, because water and snow have a high ability to reflect light.

In addition, excessive cockpit lighting can also cause glare and therefore dazzle the pilot. In this case, the glare is due to light reflected from the glass of aircraft instruments or other materials with similar properties used in the manufacture of cabin elements. This is a known problem and is usually solved at the design stage of the aircraft. To reduce the intensity of light in some cases use green or red light. This is especially true during night flights. But there is a possibility that the problem of excessive lighting may go unnoticed.

1.2 Cases of dazzling pilots from sun glare

In my search for information on dazzle of pilots from sunlight, I saw a tendency that dazzling from sunlight is more common in pilots operating small private aircraft, and in the field of commercial air transport such cases are almost non-existent. This is due to the fact that commercial airlines have a great responsibility. As a result, newer and more effective methods of combating dazzle will be used in aircraft intended for commercial transport. The pilots themselves also feel a responsibility that prevents them from neglecting the means of preventing dazzle that a pilot of his private aircraft can do.

One of the cases occurred on May 13, 2012 near Pichland, British Columbia. The plane with the floats crashed on a steep slope during the takeoff from Okanagan Valley, killing all three people (pilot, 52-year-old Colin Moyes and two of his passengers, 81-year-old Peter Brooke Keith and his 79-year-old wife Ines Helen Keith) as the pilot's vision was probably obscured by the glare of the sun, Transportation Safety Board of Canada (TSB) reports.

The TSB released a report saying the private de Havilland Beaver was facing the sun, and glare probably prevented the pilot from seeing the treetops after the plane took off from Lake Okanagan.

The report said an on-site analysis found it was in the shadows just before the accident. In addition, the pilot was looking at direct sunlight as he drove on Highway 97C in high altitude.

"As he turned north, the pilot was probably still experiencing glare related to disability, and possibly a visual illusion," the report said. "In the shade, the tops of the trees were probably not visible until the plane collided with them."

The investigation ruled out a plane malfunction or flight accident as the cause of the crash, as the plane was in good condition, and the constant speed and trajectory of the flight indicated that Mr. Moyes was in control of the plane. Mr. Moyes is also described as an experienced pilot with approximately 420 flight hours. [3]

Another similar case occurred in the state of California on February 10, 2016, in which the pilot of the Tular County Sheriff James Chavez and Deputy Scott Ballantyne were killed.

The report said that "the accident was facilitated by the pilot's inability to recognize the ascending area due to sun glare and the pilot's work, which exceeds its full weight." According to the report, at the time of the crash, the weight of the aircraft exceeded the total weight of the aircraft by 152 pounds. Being overweight caused a 30-degree stop. GPS data and eyewitnesses indicated that the plane turned left, and then the wings dropped to the left and right before the plane crashed. According to the same data, it was established that the plane was flying west over the highway at an altitude of about 500 feet above the ground.

Another pilot, who was flying shortly after the crash, said that while flying over the highway to the west, he was looking directly at the sun… and could not distinguish the tops of the hills to the left of the highway from the sky." the TSB report said. "It is likely that the pilot of the accident was partially dazzleed by sun glare and did not see the hills rising above him on the left."

The pilots flew on the Flight Design CT family, which is a high-winged tricycle, two-seater, ultralight and light sports aircraft. [4]

1.3 Cases of dazzling pilots by laser

The big problem lately has been the dazzle of pilots from the laser, or rather from high-power laser pointers. This is due to the fact that now these devices are becoming more common as they become cheaper and the places where you can buy them become more. During 2021, pilots reported 9,723 incidents of laser lighting to the US Federal Aviation Administration. This is for comparison with 6852 reports in 2020 and 6213 reports in 2019. This is 42% more than in 2020, 56% more than in 2019 and 32% more than in the previous high year of 2015 (7346 reports) (Figure 1.3.1).

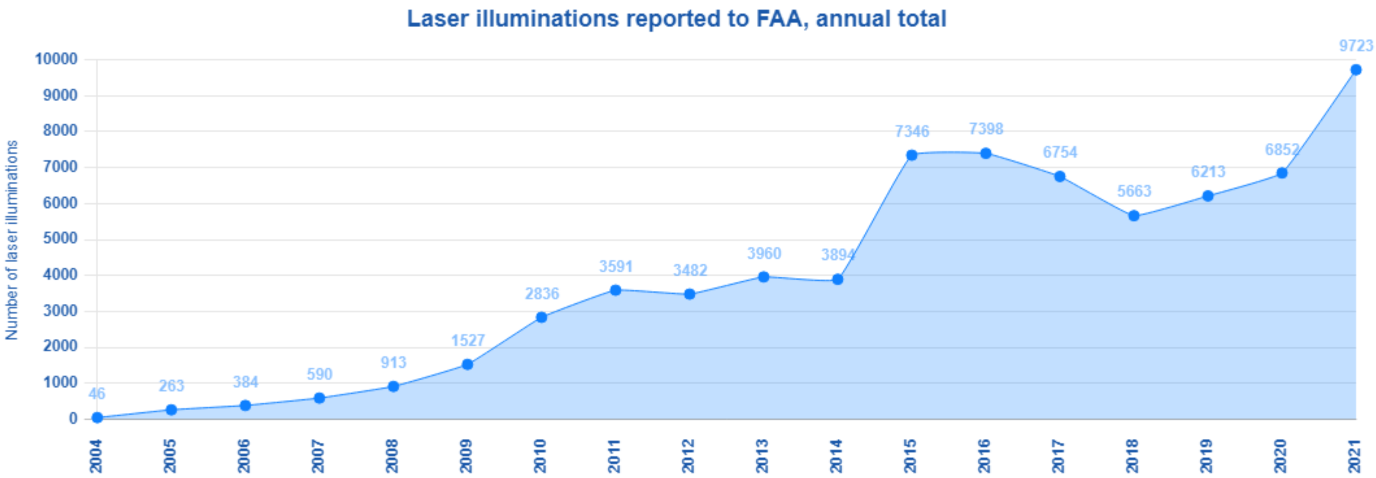


Figure 1.3.1

Below are the statistics of dazzle of pilots from Airservices Australia (Figure 1.3.2) and from Civil Aviation Authority of New Zealand (Figure 1.3.3).

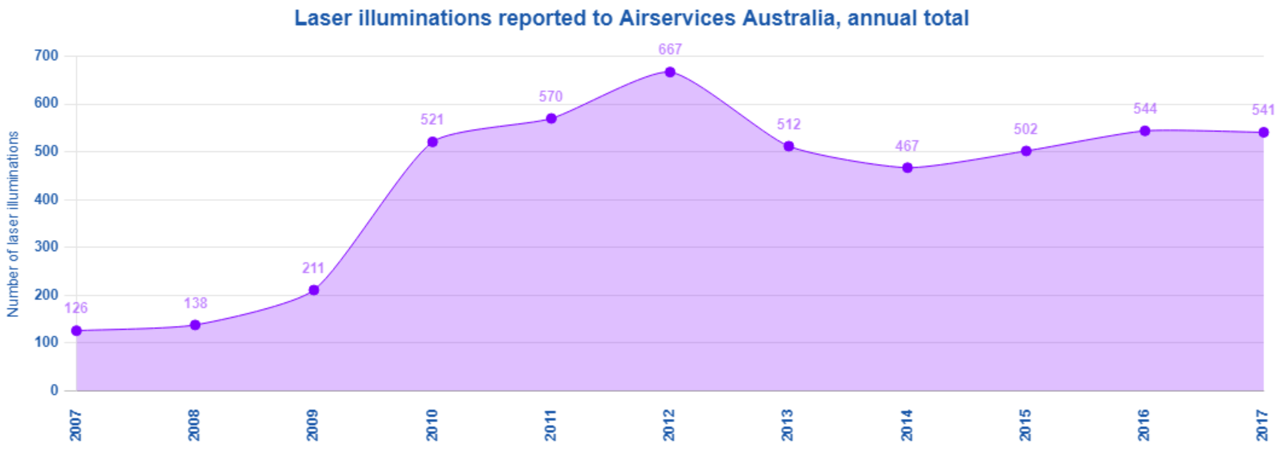


Figure 1.3.2

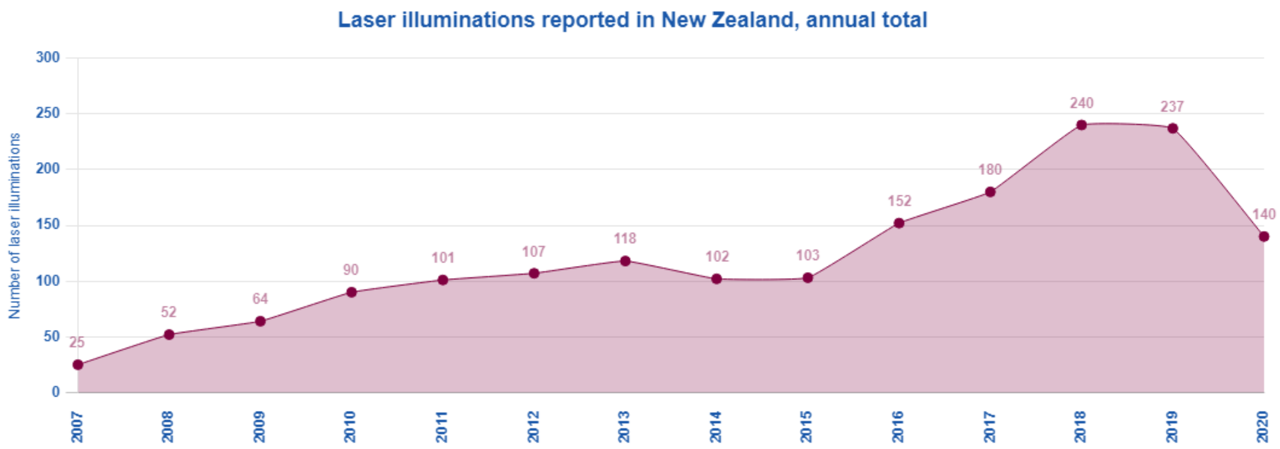


Figure 1.3.3

Such cases occur mainly at night, which is especially dangerous because it causes temporary loss of night vision. In addition to pilots, drivers of cars, cyclists, motorcyclists and others also suffer from laser pointer dazzle. Therefore, different countries have different laws governing the sale of laser pointers. [5]

Thus, on February 5, 2014, the European Union decided to ban laser pointers above class 2 with a maximum output power of 1 mW. This means that Class 3A (1-5 mW), 3B (5-500 mW) and Class 4 (500 mW +) laser pointers are prohibited from being sold and / or owned in the European Union (Figure 1.3.4).

CLASS	MAX POWER (mW)	LOGOTYPE	WARNING LABEL
1	≤ 0.39	None Required	None Required
2a	> 0.39 to ≤ 1	None Required (Exposures < 1,000 sec)	
2	≤ 1	**CAUTION**	Laser Radiation – Do Not Stare into Beam
3a	≤ 5	**CAUTION** (Irradiance < 2.5 mW/cm^2)	Laser Radiation – Do Not Stare into Beam or View Directly with Optical Instruments
		DANGER (Irradiance ≥ 2.5 mW/cm^2)	Laser Radiation – Avoid Direct Eye Exposure
3b	≤ 500	**DANGER**	Laser Radiation – Avoid Direct Exposure to Beam
4	> 500	**DANGER**	Laser Radiation – Avoid Eye or Skin Exposure to Direct or Scattered Radiation

Figure 1.3.4 Classification of lasers by power

All laser pointers sold in Europe must comply with the standards: NEN IEC 60825-1: 2014 and the General Product Safety Directive according to: 2001/95 / EC, have a technical file with ROHS and EMC tests and when they meet, receive the CE mark.[6]

In the United States, the sale of laser pointers is regulated by the Food and Drug Administration (FDA), which requires that all laser pointers sold in the United States have an output of at least 1 mW but less than 5 mW.

Items like laser pointers, called "hand-held lasers", can be legally sold with less than 500 mW if they have a lock and removable key, a two-second delay on the "on" switch and an indicator light indicating that the laser has been enabled.

Possession of a portable laser of any power is not in itself illegal under federal law, but may be governed by state or local law and subject to other laws regarding the use of the laser.[7]

As a result of research activities supported by the FAA and the Society of Automotive Engineers (SAE) G-10T (Subcommittee on Laser Safety), FAA Order 7400.2 (Part 6. Various Procedures: Outdoor Laser Work) was revised to include new guidance on Flight Safe Exposure Limits (FSELs) in specific areas of navigable airspace related to the operation of airport terminals. This review was done to increase the existing MPE, which limited exposure in the normal flight area below what could cause damage to eye tissue. MPE (Maximum permissible exposure) is the maximum level of laser radiation that a person can be exposed to without dangerous consequences or biological changes in the eye or skin. MPE is determined by the wavelength of the laser, the energy involved and the duration of irradiation.

Based on consultations with laser and aviation experts, scientific research and historical safety data, 100 microwatts per square centimeter (µW / cm2) was defined as the level of exposure at which significant blindness and post-flash images could interfere with the pilot's visual performance. Similarly, 5 µW / cm2 was defined as the level at which

significant glare problems can occur. When the laser is to be operated outdoors near an airport or air corridor, the FAA may conduct an air navigation survey to determine the airspace around the airport or airway to be protected by the appropriate FSEL. These zones and FSEL include:
-Laser Free Zones = 50 nanowatts per centimeter
squared (nW/cm2),
-Critical Flight Zone = 5 µW/cm2
- Sensitive Flight Zone = 100 µW/cm2
-Normal Flight Zone = 2.5 mW/cm2

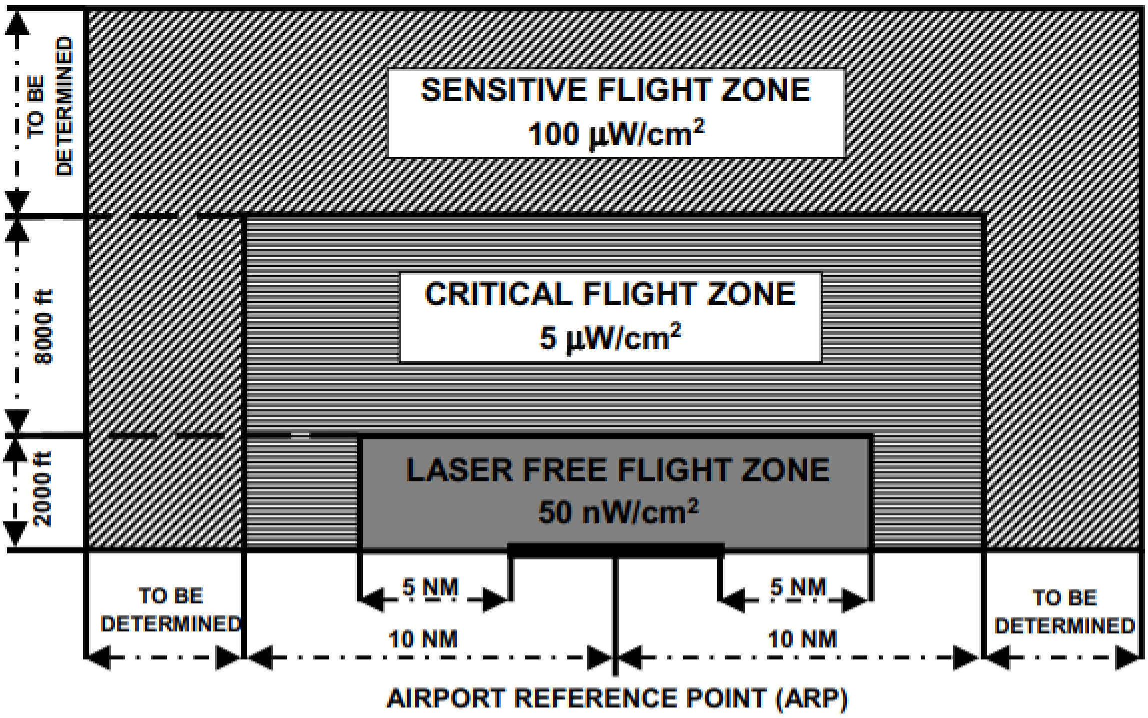


Figure 1.3.5

Figure 1.3.5 shows how the new flight zones and FSEL will be applied to an airport with a single runway. This figure does not show the Normal Flight Area (NFZ), which will be applied to the entire navigation airspace outside the Sensitive Flight Zone (SFZ). In some cases SFZ is optional and can be used based on the results of an air navigation study.
The Laser Free Zone (LFZ) includes airspace directly adjacent to the airport, up to 2,000 feet above ground level (AGL), extending 2 nautical miles (NM) in all directions, measured from the runway centerline. In addition, the LFZ includes 3 NM extensions, 2,500 feet on each side of the extended runway centerline. The critical flight zone (CFZ) includes space outside the LFZ at a distance of 10 NM from the airport control point (ARP) to 10,000 feet AGL.
But not all countries have such laws governing the sale of laser pointers. In Ukraine, for example, there is no such legislation. Therefore, in our country, the possibility of dazzle the pilot from the laser is greater than, for example, in the United States or the European Union.

There are no statistics on such cases in Ukraine, but there are a large number of complaints about this problem from pilots to the National Bureau for Investigation of Aviation Incidents and Incidents with Civil Aircraft. As an example. it is possible to result the crew of the passenger plane A320 of the Italian airline "Ernest Airlines" which carried out an evening flight from Naples. He was dazzled by a laser beam while landing at Kyiv airport. The Embrayer-190 pilots of the Lot company from Warsaw were exposed to the laser in Zhulyany. The commander of a Boeing 737, Ryan Air, flying from another Polish city, Bydgoszcz, reported being dazzled on approach to Boryspil airport. According to the National Bureau, similar facts took place in Odesa, Lviv, Ivano-Frankivsk, Uzhhorod, Kharkiv, Kherson, and Dnipro. However, even the existence of appropriate laws will not provide complete security against cases of dazzle. [8]

Also, a big problem is that laser pointers are a popular toy among children and teenagers. Unaware of the dangers of their actions, they can simply play near the airport with a laser, which can lead to a plane crash.

To determine how many pilots have negative visual effects after laser exposure to their eyes and their ability to control the aircraft, I will present data from an experiment conducted by the FAA Civil Aerospace Medical Institute. 34 pilots volunteered, among whom the average age of pilots was 40.3 years (standard deviation = 13.45; range: 22 to 70 years). One subject was female; Refraction correction (16 glasses and 3 contact lenses) was used in the trials of 19 subjects. All subjects underwent a medical examination. To assess the impact of laser light on the performance and visual characteristics of aviators used a full-flight flight simulator FAA Boeing 727-200 level C. The experiment was to from 100 feet in time to affect the object with a laser of different power levels, namely 0 μW / cm2, 0.5 μW / cm2 for 1 second, 5.0 μW / cm2 for 1 second, and 50.0 μW / cm2 for 1 second.

During the experiment, each exposure level was presented once, and the total simulation time was about 40 minutes. In total, there were four scenarios, where there were two measures with a left turn and one with a right turn of 30 degrees. A one-time test with zero exposure gave subjects a sense of uncertainty as to whether the laser would turn on during any given maneuver. The time when the laser was turned on did not seem to be a surprise factor for the subjects.

The collimated beam of green light with a peak of spectral irradiation at a wavelength of 532 nm was generated by a continuous double Nd: YAG laser. A fiber-optic cable was used to deliver the beam to the simulator's visual array. The 30o cone of scattered laser light was emitted from the fiber optic cable and delivered to the position of the object's head. A radiometer was used to measure the subject's eye exposure. Seat height was adjusted for each subject. Laser irradiation was approximately equivalent to the expected variability of eye position between subjects. The lighting came after a steady turn at 100 feet above sea level. Subjects were instructed to continue routine procedures and to fly as efficiently as possible during laser exposure. A certified laser safety operator was present during the experiment to ensure that the laser was operating safely.

For this experiment, the level of laser exposure did not exceed the maximum allowable exposure for any single exposure (19,20). The MPE for direct eye examination of a 532 nm laser beam, depicted as a point source for 1 second is 1.8 t 0.75 mJ / cm2, where t = seconds, or MPE = 1.8 millijoules per centimeter squared (mJ / cm2).

A simulation test manager was present in the cab to initiate and monitor each of the four scenarios. In addition, the cockpit operator flew as a co-pilot and was responsible for recording the subject's answers to a series of questions after each test flight. Pilots were asked to rate on a scale of 1 to 5 (1 = no, 2 = minor, 3 = moderate, 4 = large and 5 = very large) the effect of each laser impact on their ability to control the aircraft and on their visual performance. Subjects were also asked to provide any comments regarding potential exposure to radiation or vision problems. After that, the subjects filled out a questionnaire.

Table 1.3.1 shows the total frequency of visual effects reported by subjects immediately after each exposure. In some instances, subjects reported that they experienced a combination of two or all three adverse visual effects for a particular exposure. Reports of multiple visual effects increased as the laser exposure level increased (i.e., 5, 6, and 10 multiple reports, for the 0.5, 5.0, and 50 μW/cm2 exposure levels, respectively), as did reports of the more severe visual effects (flashblindness and afterimages).

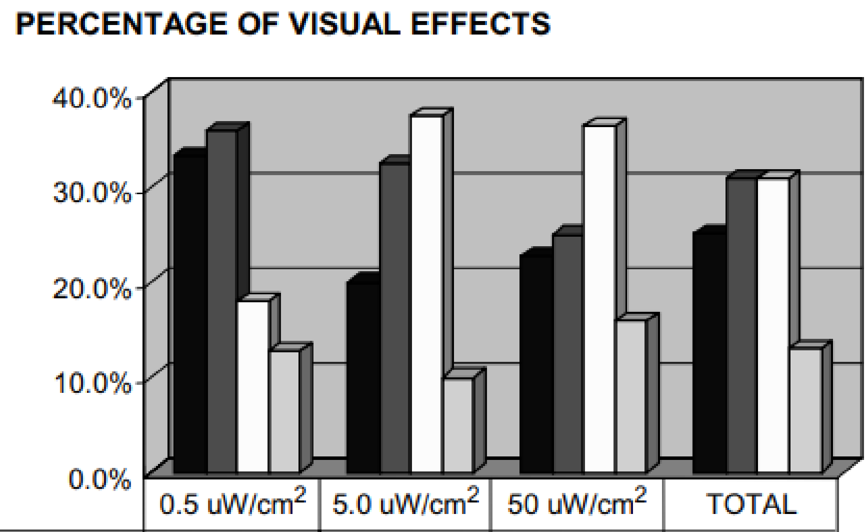
To better understand the various physiological effects, we will give them a definition:

1. Glare – obscuration of an object in a person's field of vision due to a bright light source located near the same line of sight.
2. Flashblindness – a visual interference effect that persists after the source of illumination has been removed.
3. Afterimage – a transient image left in the visual field after an exposure to a bright light.

FREQUENCY OF VISUAL EFFECTS BY EXPOSURE LEVEL				
Effects	**0.5 μW/cm^2**	**5.0 μW/cm^2**	**50 μW/cm^2**	**TOTAL**
None	13	8	10	**31**
Glare	14	13	11	**38**
Flashblindness	7	15	16	**38**
Afterimage	5	4	7	**16**
Total	**39**	**40**	**44**	**123**

Table 1.3.1

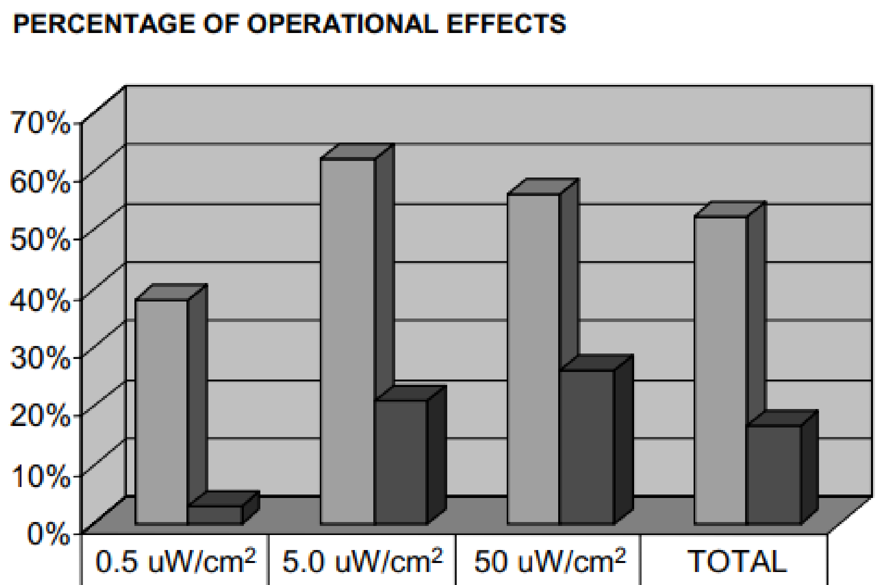
Figure 1.3.6 summarizes the percentage of visual effect responses solicited from all subjects immediately after each exposure. The most common adverse effects reported were glare (30.9%) and flashblindness (30.9%), followed by afterimage (13.0%). In 25.2% of all the responses, test subjects indicated they experienced no adverse visual effects when exposed to any of the three levels of laser irradiance.



	0.5 uW/cm2	5.0 uW/cm2	50 uW/cm2	TOTAL
NONE	33.3%	20.0%	22.7%	25.2%
GLARE	35.9%	32.5%	25.0%	30.9%
FLASHBLINDNESS	17.9%	37.5%	36.4%	30.9%
AFTERIMAGE	12.8%	10.0%	15.9%	13.0%

Figure 1.3.6

The Figure 1.3.7 and text below summarize the subjects' most frequently reported comments for the corresponding level of laser exposure.



	0.5 uW/cm2	5.0 uW/cm2	50 uW/cm2	TOTAL
VARIOUS EFFECTS	38%	62%	56%	52%
ABORTED LANDING	3%	21%	26%	17%

Figure 1.3.7

At the 0.5 µW/cm2 level of exposure, 38% of the subjects (n=13) described either being momentarily disturbed, briefly distracted, flashblinded, or loss of depth perception, visual contact with the runway surface and/or visual clues outside the cockpit. One subject felt the need to execute a missed approach or “go around” maneuver (i.e., aborted landing = 1, or 3%).

At the 5.0 µW/cm2 level of exposure, 62% of the subjects (n=21) reported various effects that included momentary flashblindness, losing view of the runway surface, loss of depth perception, and/or brief distraction. Of these, four subjects (12%) executed “go around” maneuvers, while one subject (3%) relinquished control of the aircraft to the co-pilot, and two subjects (6%) commented that they would have aborted the landing if it were a “real-world” incident (i.e., actual and potential aborted landings = 7, or 21%).

At the 50.0 µW/cm2 level of exposure, 56% of the subjects (n=19) provided comments regarding the difficulties they experienced, including having to seek shelter from the harsh light (ducking under the glare shield), momentary flashblindness resulting in the total loss of view outside the cockpit, and having to transition to instrument flight rules. Of these, four subjects (12%) executed “go around” maneuvers, while five subjects (15%) reported that they would have performed a missed approach if it were a “real-world” incident or if the duration of the laser exposure had been longer (i.e., actual and potential aborted landings = 9, or 26%) .[9]

2.Measures used in civil aviation to prevent the dazzle

2.1 Use of special matt or black paint to paint the nose of the aircraft

Aircraft nose painting has long been used to protect the pilot from glare. As Aircraft nose painting has long been used to protect the pilot from glare. As duralumin was increasingly used instead of wood in aircraft construction, the problem became more acute. This was especially true for American airlines, which often did not paint their planes completely. Often not the whole nose was painted, but only a small part near the windshield. Initially, they used glossy black paint. This method was used in both civil (Figures 2.1.1) and military aviation (Figures 2.1.2).

Figure 2.1.1 DC-3

Figures 2.1.2 P-47

When weather radar was installed in the bow, the radom was made of fiberglass composite instead of shiny duralumin. One of the properties of this radom is its non-metallic and non-reflective surface to minimize the reflection of the transmitted signal from the radom back to the antenna, which can damage the receiver crystal. The nose of the plane was still painted black for some time, because it had low reflectivity (Figure 2.1.3).

Figure 2.1.3

Over the past few years, meteorological radars for civilian aircraft have undergone rapid improvements. In particular, the ability to see through different colors has improved. Modern radars can compensate for any color of the radom and provide the same image quality In modern aviation use a special matte paint that reflects almost no light, and therefore today the nose of the aircraft is painted according to the color of the fuselage.

All modern aircraft usually use special oil-based polyurethane paints for nose painting; because they are durable, UV-resistant, and better resistant to thermal and mechanical shocks. But because oil-based polyurethane paint is more toxic and less environmentally friendly than water alternatives, there may be many state and local restrictions and safety regulations on aircraft painting.[15]

2.2 Glasses

2.2.1 Sunglasses

Sunglasses are one of the easiest ways to protect a pilot from sun dazzle during takeoff and landing. They are quite inexpensive to manufacture, and, unlike other methods of protection against dazzle, their use does not require structural changes in the aircraft. In addition, they can be easily removed and put on, which makes them easier for pilots to use, as it allows them not to be distracted during takeoff and landing. Aviation uses different types of glasses, which are used for different tasks and in different conditions. Some glasses have better protection from ultraviolet light, others are used in cloudy or foggy weather. In addition, for different pilots glasses are selected individually depending on their age, physiological characteristics, etc. The wearing of glasses is strictly controlled, because their improper use can lead to a plane crash. Since we are interested in the dazzle of pilots, we would consider glasses with lenses that protect the eyes from glare. [17]

The first thing that came to my mind were glasses with polarizing lenses. But pilots are not allowed to wear them. The U.S. Aviation Medical Advisory Service (AMAS) explains: "Pilots should not wear polarized lenses in the cockpit. Glare from flat surfaces is blocked by polarized lenses oriented by parallel lines, as close to the prison bars. Light parallel to the lines (glare) is blocked. Unfortunately, if the windshield is polarized and the lenses are not oriented exactly like the windshield, all the light can be blocked. Changing the angle and position of the head can create blind spots. " AMAS recommends using bright or polycarbonate lenses of a neutral hue (green or gray) that block 70-90% of the incoming light, possibly with a gradient that illuminates at the bottom of the lens, on bright days when the sun is particularly likely to bedazzled.

The three most common lens materials used today are crown optical glass, monomeric plastic (CR-39®) and polycarbonate plastic (Figure 2.2.1.1).

Material Properties	Crown Glass	CR-39 Plastic	Polycarbonate
INDEX OF REFRACTION Higher number = thinner lens	1.523	1.498	1.586
SPECIFIC GRAVITY Higher number = heavier lens	2.5	1.32	1.20
DISPERSION (Abbe value) Higher number = fewer aberration	59	58	31
STRENGTH	Temperable	Strong, SRC required	Strongest, SRC applied to lens blank
CHARACTERISTICS	Coatable, easily fabricated, readily available	Tintable, coatable, easily fabricated, readily available	Coatable, special fabrication equipment required, recommended for children and athletes

Figure 2.2.1.1

Crown glass has better resistance to stains than plastic, but it is heavier and does not withstand shocks. Glass absorbs some of the ultraviolet light; however, absorption is improved by adding certain chemicals during the production process or by applying a special coating. In addition, lenses made of crown glass have excellent optical properties. CR-39 plastic lenses have excellent optical properties, are lighter in weight and more resistant to impact than glass lenses, but are easier to scratch, even if scratch-resistant coating (SRC) is applied. The CR-39 lenses tint easily and evenly, even for those who require significant refraction correction but do not retain shades as well as glass. The main advantage is that CR-39 plastic can be bleached and repainted if the lenses fade.

Polycarbonate plastic lenses are lighter than CR-39 and are the most impact-resistant lenses. Polycarbonates have a low Abbe value, which indicates their inherent optical aberrations. The use of anti-glare (AR) coating can improve the optical quality, especially when high refractive error is required. These lenses have built-in UV protection and are made with a scratch-resistant coating that is much stronger than CR-39 lenses. The main disadvantage is that polycarbonate lenses do not absorb dye as easily as CR-39® plastic, they are less suitable for use as sunglasses. However, the internal anti-scratch coating will absorb shades. [18]

2.2.2 Glasses for laser protection

The use of special goggles to counteract the dazzle of pilots with lasers is currently quite relevant. Its advantages are the same as in sunglasses. Due to the fact that the problem of dazzle pilots with a laser is relatively new and only becomes more relevant over time, many companies are looking for a solution to this problem through the production of specialized glasses. Green lasers are the most common, so lenses with a green wavelength filter are usually used in glasses. However, blue or red wavelength filters or combinations thereof with a green wavelength filter can also be used.

As we can see from the Figure 2.2.2.1 , at night and during the day can be used lenses of different colors. Used night lenses provide almost three times more transmission of visible light than day lenses to maintain visibility in the dark.

Figure 2.2.2.1 Visors that prevent dazzle of pilot by laser: in day(left), in night(right)

However, universal lenses can be used that can be used at different times of the day (Figure 2.2.2.2)

Figure 2.2.2.2

Usually, lenses for such glasses are made of polycarbonate plastic. A special filter layer is applied to the inner surface of the lens.

The main characteristics for such glasses are two parameters: optical density (OD), visual light transmission (VLT). Sometimes the percentage of light absorption from the laser is still taken into account, but this is not so important, because it is constantly large in such lenses (in the range of 95% -99%). Usually, the larger the VLT parameter, the lower the percentage of absorption of the laser beam and vice versa

Optical density (OD) is a measure of the attenuation of energy passing through a filter. The higher the OD value, the higher the attenuation and the higher the level of protection. In other words, OD is a measure of the energy of the laser that will pass through the filter.

Visible light transmission (VLT) is a measurement of the amount of light waves transmitted through a material. [31]

For comparison, I chose several types of glasses with laser glare protection from different manufacturers. I took information about their characteristics from the manufacturers' websites, so I can't guarantee its reliability. For comparison, I took:

- two models of Phillips Safety glasses: with LS-PSPG lenses (which protect only from green laser light) and with LS-PSPBGR lenses (which protect from green, blue and red laser light);[24]
- three models of GlareShields from NoIR, which was developed with the participation of helicopter pilots of the Los Angeles Police Department PBG (reduces green and blue), AG2 (reduces green) BGR (designed for full sun; it reduces green, blue and red);[25]
- two models from Gentex: for day and night.[23]

	VLT	Optical density, OD		
		Green	Blue	Red
Phillips Safety glasses with LS-PSPG lenses	46.9%	2+	-	-
Phillips Safety glasses with LS-PSPBGR lenses	23.3%	1,5+	1,5+	1,2+
NoIR PBG	49%	2,5+	1,5+	-
NoIR AG2	53%	2+	-	-
NoIR BGR	29%	1,5+	1,5+	1
Gentex for day	15%	2,5+	1,5+	0,8+
Gentex for night	30-40%	2,5+	1,5+	-

Table 2.2.2.1

After analyzing the information I received while compiling the table 2.2.2.1, I came to the conclusion that it is difficult to make lenses that would protect equally well from green, worm, and blue colors, as well as specialized lenses for each color of laser. In addition, this leads to a decrease in VLT, which is especially dangerous during night flights.
But such glasses that prevent dazzle of pilots from the laser has a big disadvantage. The filter through which the light passes can distort the color of objects. Let's analyze this shortcoming based on glasses with protection against the green laser.
As glasses with green filters reduce the amount of green light available, any remaining light will become dominant. In the case of a green filter in a laser eye protection device, the green light may look dimmer and more yellow in color. This can lead to green lights being confused with aviation white and yellow lights. Glasses with a green filter can cause color illusions, which are tired because white and yellow lights look red and can potentially interfere with some green and blue lights.[2]

2.3 Anti-glare shields and sunvisors

2.3.1.Anti-glare shield

During the take-off and landing stages, there is a possibility of dazzling the pilots with the light of the flight, which was reflected from the glass surface of the instruments. also, the glare generated prevents pilots from receiving information from the instruments. To prevent this problem, special anti-glare shields are installed in aircraft. In large commercial aircraft, these shields are basic and are installed on all aircraft. On small planes, especially on older models, they may be absent. Instead, on small private planes, they can be installed as an additional unit.[26]

Figure 2.3.1.1. Anti-glare shield in Boing 737

(1)

(2)

Figure 2.3.1.2 Anti-glare shield for airpalne RV-10 : top view(1), inside view(2)

However, the manufacture of the shield itself and the choice of material must comply with parts of the Federal Aviation Regulations (FAR), namely:

1) Part 23 - Airworthiness standards: normal category airplanes;
2) Part 25 - Airworthiness standards: transport category airplanes

Typically, such shields are made of carbon or fiber with epoxy resin. Fiberglass is sometimes used instead of carbon fiber. Paint the finished product in dark colors (mostly black. Sometimes covered with a special fabric or leather also dark colors. [27]

2.3.2 Sun visors

Sun visors provide dazzling of pilots in the same way as glasses. The advantage of this visor is that it is stationary, unlike glasses, which you can forget to take with you. Visors can be found on all types of aircraft. Depending on the types of protective fabric, glare protection can be from 80% to 99%. There are also different types of visors for mounting:

1. Stationary hinged mounting (Figure 2.3.1.1);
2. As an overlay on glass (Figure 2.3.1.2)
3. RAM suction cup, small double socket arm (Figure 2.3.1.3).

Figure 2.3.1.1

Figure 2.3.1.2

Figure 2.3.1.3

In commercial aircraft, stationary hinges are used, because the visors are often installed at the request of the buyer at the factory. In addition, this type of mount is the most reliable of the latter. Its biggest advantage is that it can be easily folded after the take-off or landing stage. And options with an overlay or a sucker are used for small private planes.

Lighter strength composite and cast acrylic are used to make the visor protective fabric in the stationary hinge and suction cup versions. In case of fastening of type of an overlay on glass transparent polymer is used. This type of fastening is that the protective fabric clings to any smooth surface due to its static electricity.

If I choose one of these fasteners, I would choose a hinged fastener because of the benefits I will name above. The other two clips I think are not very reliable, and therefore safe enough for use in aviation. Especially a lot of negative statements when finding information I found about the type of mounting pad on the glass.[28]

Returning to the use of visors in commercial aviation, I found a comment from a pilot flying an A320:

Surprisingly, there is a huge amount of discussion when it comes to the use of sun visors. I have reviewed the A320 FCOM (Flight Crew Operation Manual) several times and found no restrictions on the use of sun visors, nor anything in the QRH (Quick Reference Handbook). Many of the training captains I met told me not to use them during takeoff and landing because they were in danger if they came off, and different airlines and countries have different laws for using sun visors. legally in the United States and Europe, but I'm not sure in Asia. "

From this we can conclude that the safety of the use of visors is not solved. In my opinion, if you choose between sunglasses and a visor, sunglasses will be more comfortable and safer to use. The only advantage that the visor has I voiced above, namely the fact that he is constantly on the plane, is different from the glasses, which can be forgotten. Therefore, it is advisable to install it as a precautionary measure in case the pilot forgot his glasses. I would also like to point out that this method is not used to prevent laser dazzle. [29]

I would like to single out the sun visors using the Head Up Display (Figure 2.3.1.4) . HUD - Head Up Display is a means of presenting information to the pilot in the line of his external front vision, which projects the key data of flight instruments on a small "transparent" screen located directly in front of the line of sight of the pilot. ahead of the plane. This technology has long been used in military aviation, but for commercial aviation this system has become available relatively recently. This visor has two functions: protection of the pilot from dazzle, improves tracking of pilots for flight information. But because the viewfinder screen must be relatively transparent, the pilot's protection against glare will be less than when using a conventional sun visor.[30]

Figure 2.3.1.4

3. Promising measures to prevent the dazzle in civil aviation

3.1 LEP materials

Laser eye protection (LEP) is a protection against glare, the main element is filters. In paragraph 2.2.2, when I talked about goggles, I superficially touched on this topic. As a rule, all LEP filters can be classified as absorbers (polycarbonates impregnated with dye and colored glass), interference materials or power limiters. These classes are discussed according to their strengthening characteristics and any of their limitations. For the production of filters used materials such as:

- Polycarbonates impregnated with dye are available with different filtration capabilities. The material is made by uniformly dispersing one or more dye absorbers throughout the polymer medium. Optical densities are easily changed by the concentration of the dye absorber, and the formation of various shapes is possible. However, some polymers, after some time lose the ability to filter due to aging or exposure to sunlight (solarization).
- Stained glass, consisting of dissolved or suspended dyes in glassy materials. These filter materials are uniform, do not change due to minor scratches and have excellent optical quality. The optical density of colored glass is difficult to control during manufacturing; instead, the optical density is usually determined by the thickness of the glass. However, glass also suffers from solarization.
- Interference filtering materials, including holographic lattice and dielectric gratings. They are a wide class of materials that rely on light interference to ensure their filtration capabilities. The most important feature of this class of filter materials is that extremely narrow bands (up to 5 nm) are possible, which gives the material light transmission of the filter. However, all these materials have a strong dependence on the angle of incidence of radiation, ie it best filters light at a right angle.
- Non-linear optical materials or power limiters. These materials include optical switches and liquid crystals. Such materials are designed to transition from transparent to opaque when radiation exceeds a specified threshold. The limiters were designed to counteract nanosecond pulse threats in a wide spectral range.

To compare the effectiveness of the various materials used to make LEP filters, I will refer to a study by senior research enginee Jeanne A. Welch, which she added to her report "Review of materials for laser filters".

Table 3.1.1 presents a more detailed list of materials and their combinations that have been selected as the most effective in combating laser glare.

1	FV2
2	FBI/BG39
3	Argon ion/BG39
4	FBI/KG3
5	Argon ion/KG3

Table3.1.1

Table 3.1.2 presents the VLT of these materials. I mentioned the significance of this parameter in paragraph 2.2.2.

Materials	VLT
FV2	24 %
FBI/BG39	35 %
Argon ion/BG39	31 %
FBI/KG3	40 %
Argon ion/KG3	35 %

Table 3.1.2

BG39 (Schott Glass Technologies) and KG3(Fred Reed Optical) are colored glass materials that provide infrared hardening. Due to the fact that it does not protect against lasers with a wavelength of 440-565 nm, ie from the most common green and blue lasers, the study uses only a combination of these materials with others as additional protection.

Two materials that are a good option for laser hardening in green are the ionic polymer Glendale Protective Technologies Argon and the Gentex FBI polymer. Both materials provide protection against mechanical damage. Both also provide UV protection. Glendale Protective Technologies FV2 provides adequate protection in all specified laser regions. But at 488 nm, the reflectance of the LEP is approximately 20%. This is higher than expected for an ordinary spectacle and suggests that specular reflections from this LEP are potential hazards. The LEP protects throughout the infrared and is suitable to counter Alexandrite lasers (infrared spectrum 755 nm).

For the human eye, the combination of the transmittance of the eye, the conditions of illumination and the filtering of the visible spectrum gives the illumination of the photometric flux (lumens) reaching the surface of the retina. The Formula 3.1.1 was derived to obtain graphs:

$$E_f = \int \tau_f(\lambda) * f_{eye}(\lambda) * f_{light}(\lambda) dl \qquad (3.1.1)$$

Where

$\tau_f(\lambda)$-is the transmittance of the filter,

$f_{eye}(\lambda)$- is the photopic or scotopic transmittance of the eye (Figure 3.1.1),

$f_{light}(\lambda)$- s the incident spectrum.

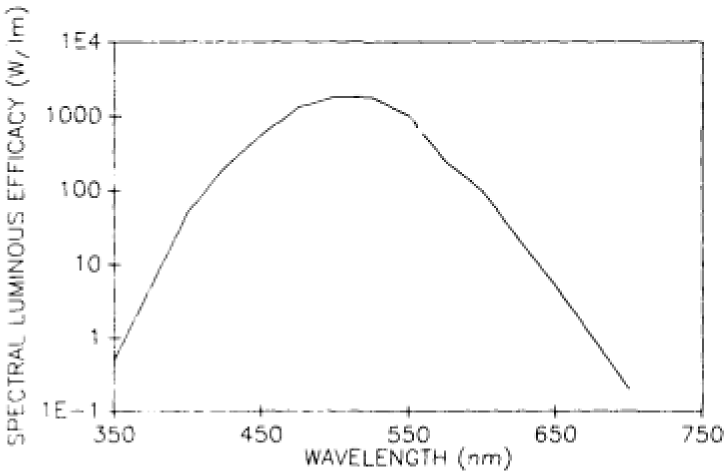


Figure 3.1.1 Spectral response of the human eye

For a better understanding of the figure 3.1.1 I will give the definition of spectrial luminous efficacy. Spectrial luminous efficacy is the relative efficiency of detection, of light or other signal, as a function of the frequency or wavelength of the signal. The experiment was performed under day and night lighting.
For incident spectral measurement, an installation was made, which is shown in figure 3.1.2.

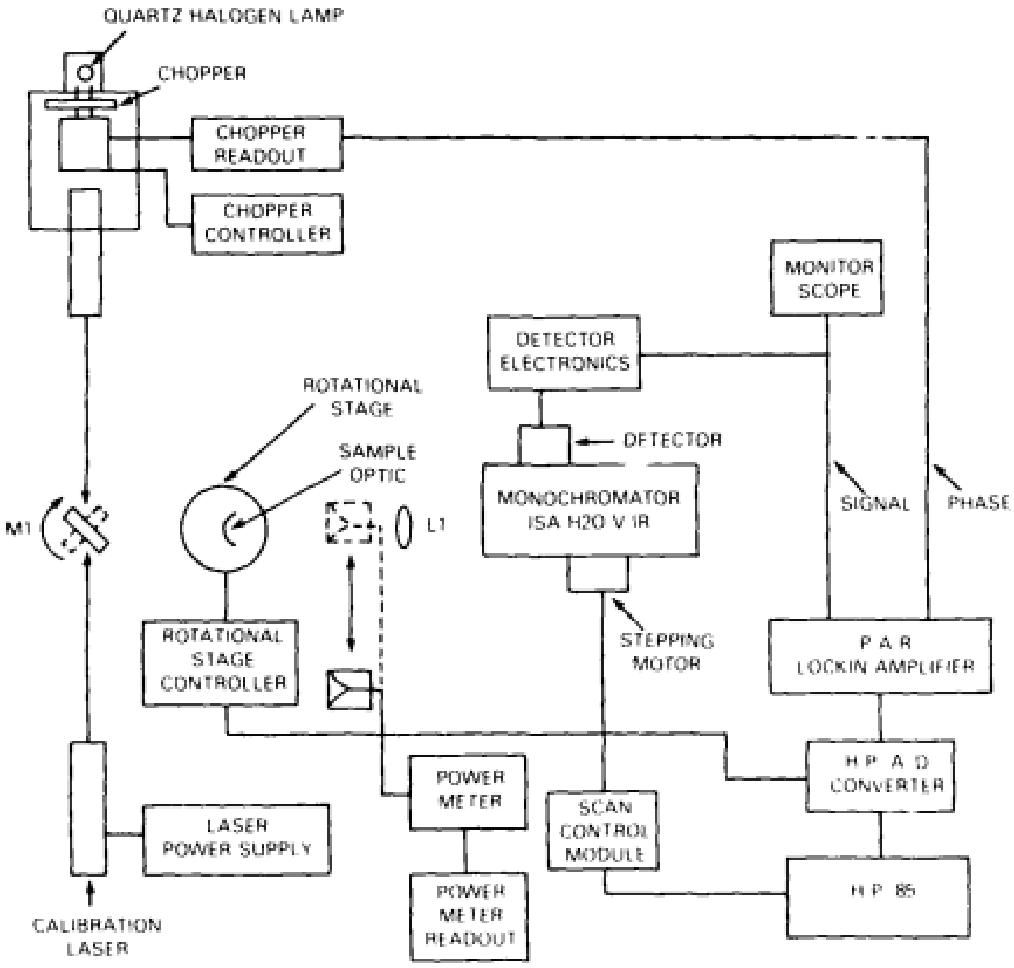


Figure 3.1.2

The 0.2 m diameter Instruments SA monochromator has a holographic grating with a stepper motor, 800 grooves / mm, 600 nm lightning with a spectral range from 300 to 1100 nm. Input and output slits of 0.5 mm give an equivalent slit width of 3 nm. For each measurement, the spectrum from 400 to 1100 nm was covered by 233 steps with a limited resolution of 3 nm.
The light source for spectral measurement was a quartz halogen lamp with tungsten filament. The output beam fell perpendicular to the filter. Several investigated materials for laser hardening were cast with curved surfaces. To reduce interference in the signal from diffracted light incident at angles other than normal, the beam was narrowed to 0.3 cm with a diaphragm. To eliminate background noise, the source was chopped at 370 Hz.

Stanford Research Systems Model SR530 or PAR Model 5204 amplifier with a time constant of 0.3 s was used for data collection. To facilitate data collection and analysis, the original lock data was processed using the HP59313A analog-to-digital converter and the HP85A desktop computer.[32]

As a result of measurements and calculations, the following graphs were obtained (Figures 3.1.3-3.1.12):

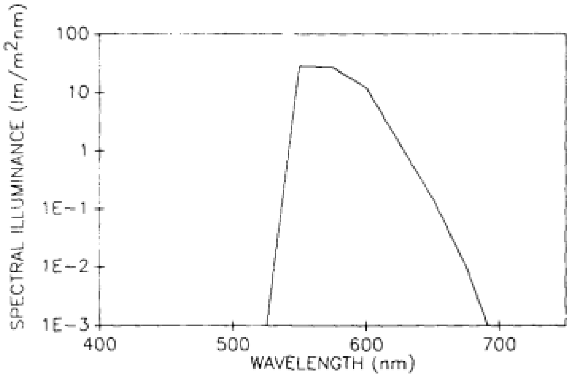


Figure 3.1.3 FV2 daylight illuminance

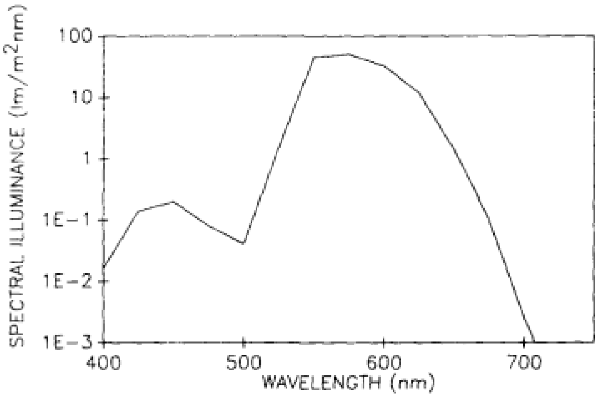


Figure 3.1.4 FBI/BG39 daylight illuminance

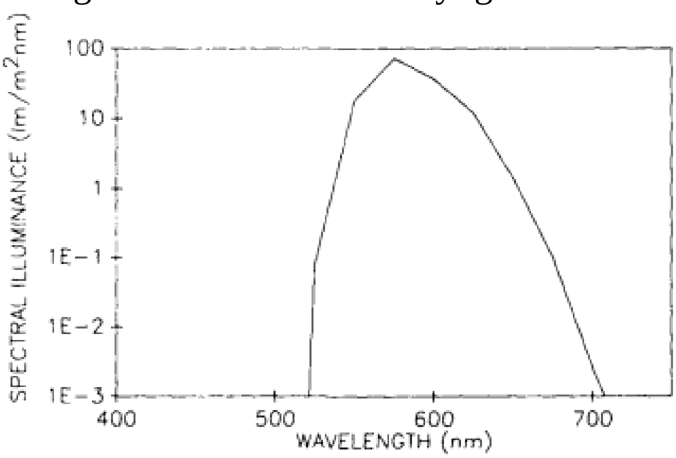


Figure 3.1.5 Argon ion/BG39 daylight illuminance

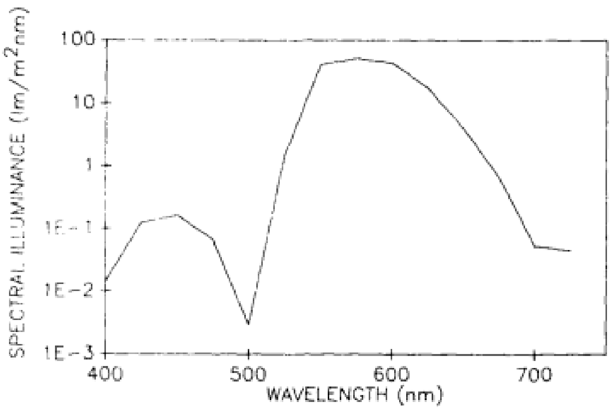


Figure 3.1.6 FBI/KG3 daylight illuminance

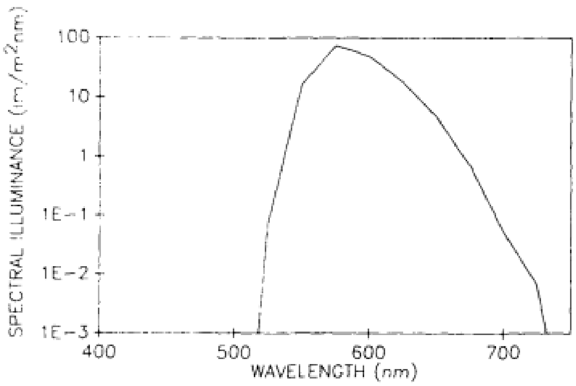


Figure 3.1.7 Argon ion/KG3 daylight illuminance

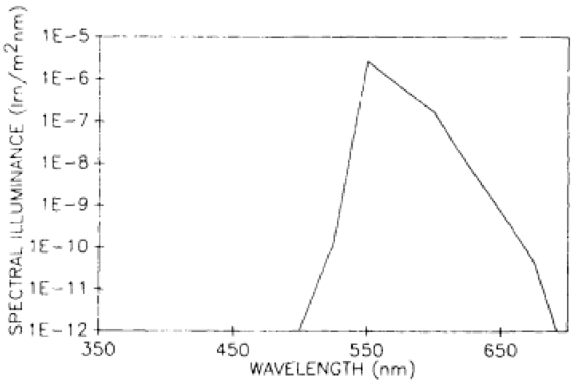


Figure 3.1.8 FV2 nightlight illuminance

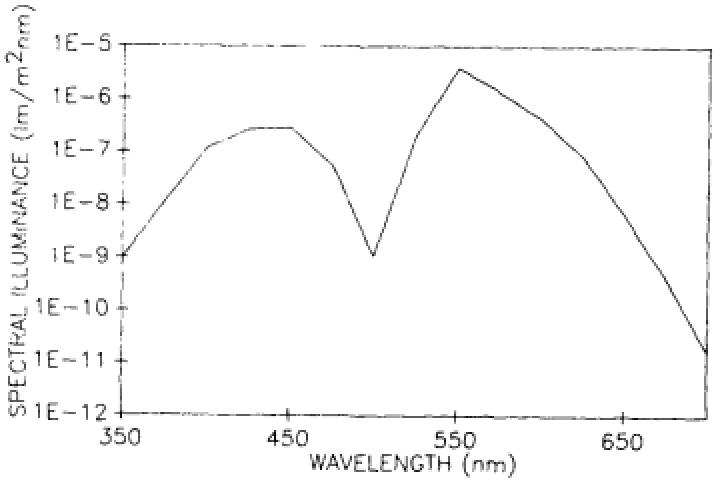


Figure 3.1.9 FBI/BG39 nightlight illuminance

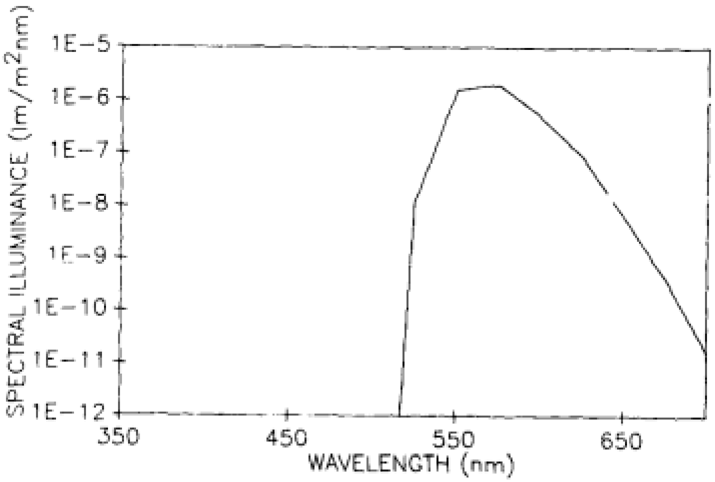


Figure 3.1.10 Argon ionIBG39 nightlight illuminance

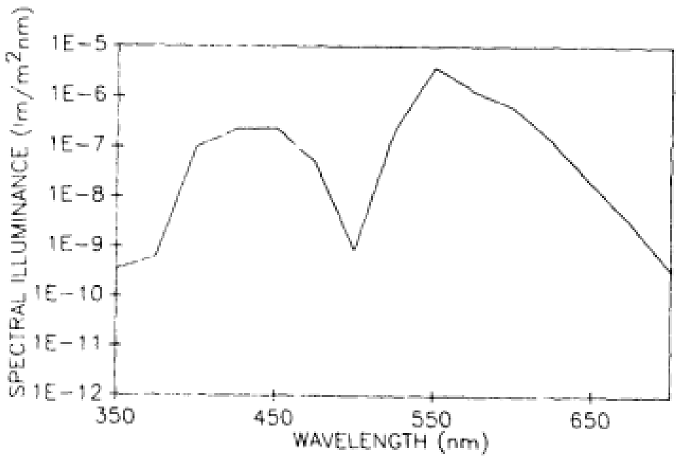


Figure 3.1.11 FBI/KG3 nightlight illuminance

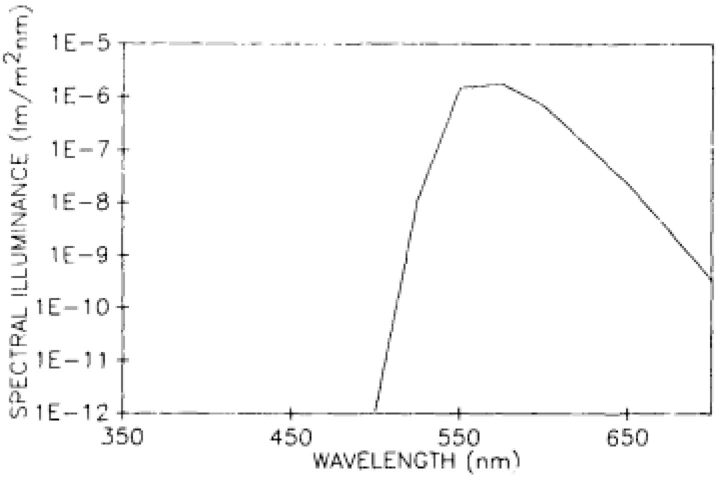


Figure 3.1.12 Argon ion/KG3 nightlight illuminance

To determine the best filter material for commercial aviation (namely, green laser protection) from a sample of the experiment for day and night use should be taken into account and VLT (Table 3.1.2.). To better understand the graphs in Figures 3.1.3-3.1.12, it should be borne in mind that illuminance is the total luminous flux incident on the surface per unit area. So we can conclude that the lower the function curve, the better the filter protects from light of a given wavelength. Therefore, to determine the best filter, VLT and spectral illuminance at 500 nm to 565 nm wavelengths must be taken into account.

For use during the day, based on spectral illuminance, the materials Argon ion / BG39 and FV2 proved to be the best. But if you take into account VLT, then Argon ion / BG39 shows itself better than FV2, namely 31% has Argon ion / BG39 and 23% has FV2.

In the case of choosing filters to reduce the prevention of laser light at night, not everything is so clear, because the main criterion in this case will be VLT, because the transmission of the maximum number of photons is critical at night. In this case, the FBI / KG3 material with 40% VLT proved to be the best. On the other hand, Argon ion / BG39 and Argon ion / KG3 proved to be the best in terms of protection efficiency. If you choose between these two materials including VLT, the best result is in Argon ion / KG3 with 35% VLT.

3.3 The optical power limiter

One of the problems with optical spectral filters used in goggles to protect against laser radiation to prevent dazzle from being dazzled by the laser is that they block the entire wavelength permanently. As I mentioned in paragraph 2.2.2., This leads to visual illusions associated with the change of color of some objects, which negatively affects the pilot during takeoff and landing.

Instead, there are experimental nonlinear, solid-state dynamic filters that limit light transmission only if the power exceeds a certain threshold. One such experimental setup was presented at the 2012 year SPIE Defense, Security, and Sensing conference in Baltimore. It was developed by Ariela Donval, director at Elbit systems Ltd.

 The anti-glare unit consists of a Pulnix TM-7EX camera, which looks at the picture illuminated by a flashlight. A continuous laser with a wavelength of 532 nm (ie the color of the laser is green) is introduced into the optical path through a mirror. The laser and flashlight pass through the same optical path, which consists of an input lens and an output lens with a anti-glare filter in between. After that, the general light falls on the camera (Figure 3.3.1).

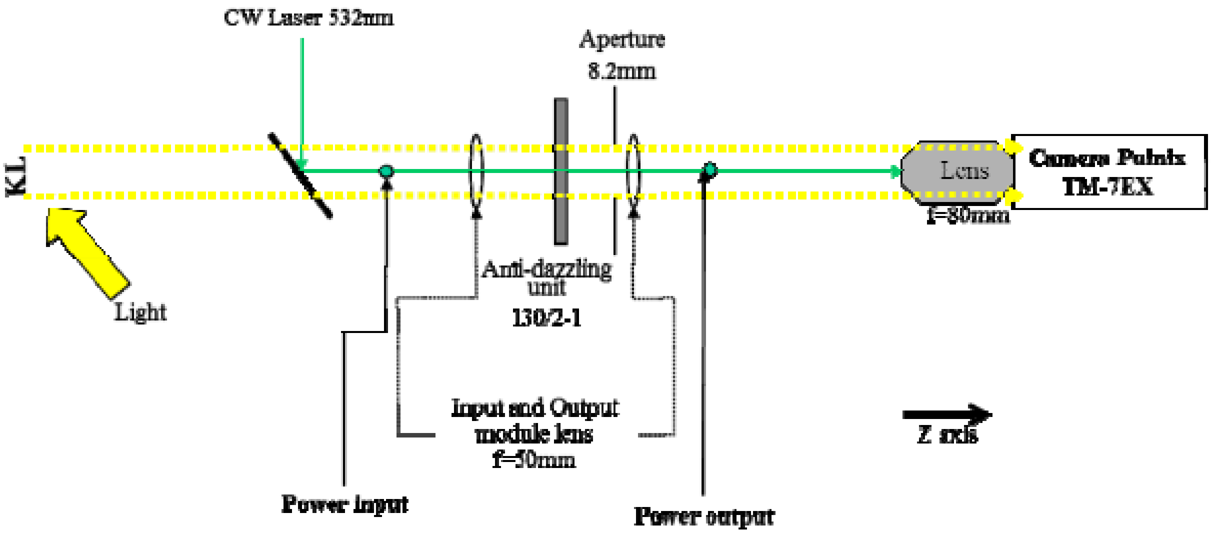


Figure 3.3.1

 Power is determined at two points, which are shown in Figure 3.3.1 as input and output power. The anti-glare filter moves along the z-axis in and out of focus. When the filter is set to z = 0, e.g. at the focal point of the lens, limiting behavior is most effective.
The main function of the optical power limiter is to limit or fix the output power of the filter to a certain level (namely, the power limit). At low input powers, the limiter is transparent, while at input powers above the limit power, the output power is constant. The action of the optical power limiter is reversible; that is, when the input power drops to the limit level, the optical power limiter becomes transparent again.
 Figure 3.3.2 shows an experimental graph of the dependence of output power on input power. The curve shows the characteristic behavior of the anti-dazzling limiter. From the graph we can see that when the sample is placed out of focus, the output power curve is a relatively straight line. At the same time, the curve representing the output power for the same sample when it is placed in focus has the form of radical graph.

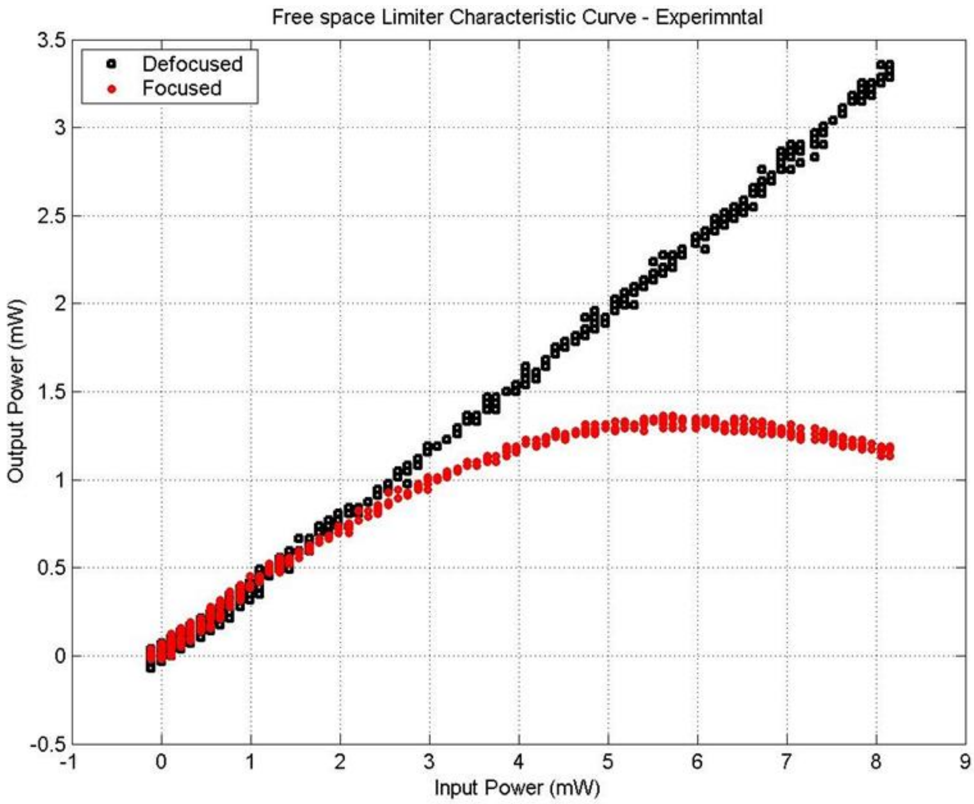
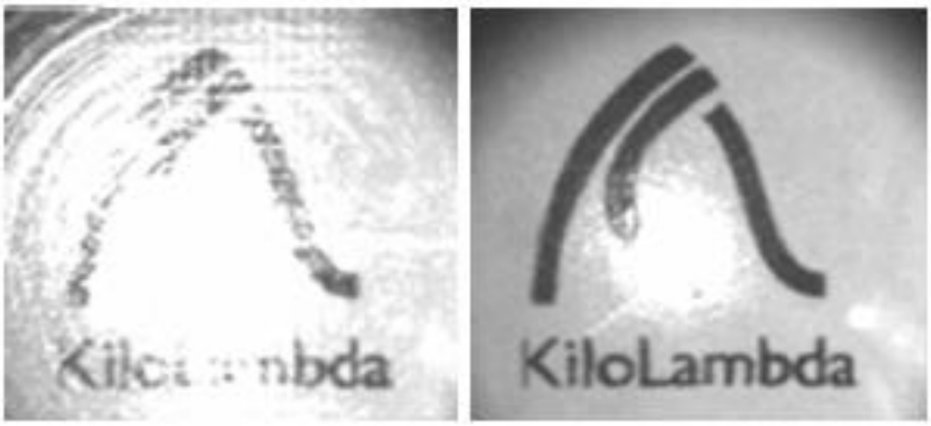


Figure 3.3.2. Anti-dazzling limiter characteristic curve

From the curve we can learn that the linear transmission of the filter is 50%, and that the maximum output power in this case is measured as 1.3 mW.

The introduction of such a filter near the camera sensor limits the dazzling effect of high laser power and at the same time we can see a clear image without much glare. In Figure 3.3.3 we can see two photos that were taken using the anti-dazzle filter and without it.[36]



a) b)

Figure 3.3.3 Anti-dazzling demonstration using anti-dazzle limiter. Left – without introducing the limiter; right – when introducing the limiter between laser and camera.

This development was presented for use in military aviation, but it can also be used in commercial aviation. The advantages of this method include the fact that it does not change the color of objects, unlike anti-glare glasses. In addition, this design is effective against any laser aimed at the aircraft, because the filter is broadband and does not depend on the wavelength. Disadvantage is that unlike glasses, some of which can protect against laser light of different wavelengths, albeit with a decrease in visible light transmission, which filter can protect against only one wavelength of the laser beam.

Conclusion

Dazzle of pilots in the take-off and landing stages from the sun is a long-standing problem that arose immediately after the spread of aviation as a means of transportation. During this time, there have been many different methods to combat this problem. In particular, one of the most effective methods is the use of sunglasses, the advantages of which I mentioned in paragraph 2.2.1. Dazzling pilots at the stages of takeoff and landing from the sun occurs mainly when flying on small private planes. This is due to the fact that commercial aircraft have implemented a sufficient number of methods to combat this problem, in contrast to small private aircraft where these methods are optional and many people neglect their implementation.

Instead, the problem of dazzle of pilots in the take-off and landing stages from the laser is a fairly new problem, and based on Figures 1.3.1-1.3.3, we see that it has become widespread and dangerous since 2004-2007. Therefore, many companies are trying to solve by developing special countermeasures. LEP filters are one of the most successful means of anti-dazzling pilots during the take-off and landing stages. In Section 3.1, we compared some LEP filters based on research information and selected the best ones for commercial aviation conditions. Particular attention should be paid to the experimental material optical power limiter, which due to its characteristics can be quite successful in solving the problem of dazzle pilots at the stages of takeoff and landing from the laser.

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