COVER PAGE

Title of Design: Mitigating Laser Attacks in Critical Flight Zones

Design Challenge Addressed: Runway Safety/Runway Incursions/Runway Excursions

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Mitigating Laser Attacks in Critical Flight Zones

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Executive Summary

The new term "lasing," coined by the Federal Bureau of Investigation (FBI), refers to the dangerous practice of deliberately or accidentally pointing a laser at an aircraft, potentially harming pilots and passengers. Laser illuminations, or laser strikes, have increased approximately 1300% over the last nine years and, according to the FBI, are expected to continually increase in the next decade, unless dealt with accordingly. Plans initiated by the United States government, Federal Aviation Administration (FAA), and FBI include programs and tough new laws enacted to bring attention to the seriousness of this crime. Currently, under the United States Patriot Act and the FAA Modernization and Reform Act of 2012, it is a federal offense to shine a laser at an aircraft. In February 2014, the FBI initiated a $10,000 reward to help apprehend anyone shining lasers into aircraft, the same reward for reporting a "cop shot" in New York City. However, laws alone will not stop criminals from trying to bring down an aircraft using laser beams given the relative ease of acquiring and using these lasers. An active approach needs to be taken to eliminate the risk of laser strikes altogether. *Mitigating Laser Attacks in Critical Flight Zones*, proposed by an international team of nine undergraduate students at Binghamton University – State University of New York, is an active approach aimed at stopping directed laser illuminations from affecting pilots during all flight phases.

The first and primary step of the solution is to install a laser-blocking visor into all commercial aircraft. This visor will contain a laser filtering film that will stop laser light from affecting the pilots' vision. The second step to this approach is to include laser protective glasses in all aircraft. These glasses will be placed on a clip attached to the yoke's clipboard in the cockpit, within easy reach of a pilot when faced with a laser attack.

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I. Problem Statement and Background

i. Lasers and Laser Illumination Attacks

Lasers are common instruments in today's society. These concentrated beams of light are useful in many disciplines, and thus have been a focus of technological development. Lasers come in varying wavelengths, measured in nanometers (nm), which indicates their color. Meanwhile, a laser's potency, which is more commonly known as power, is measured in watts (W) or milliwatts (mW). Due to their usefulness, lasers have been very well developed and are now available as hand-held devices.

Figure 1 - A green laser illuminates the interior of a cockpit [10]

A laser illumination attack occurs when a person on the ground points a laser beam towards an aircraft's cockpit. A pilot may be blinded, startled, or stunned by the sudden appearance of the concentrated beam of light, as shown in Figure 1. These attacks have resulted in the disruption of airport traffic patterns and have increased safety risks within the FAA's "critical flight zones." The critical flight zone is defined as the area within ten nautical miles of an airport runway, shown in Figure 2 [1]. In at least 35 cases, pilots have suffered from eye injuries due to laser illumination attacks [2].

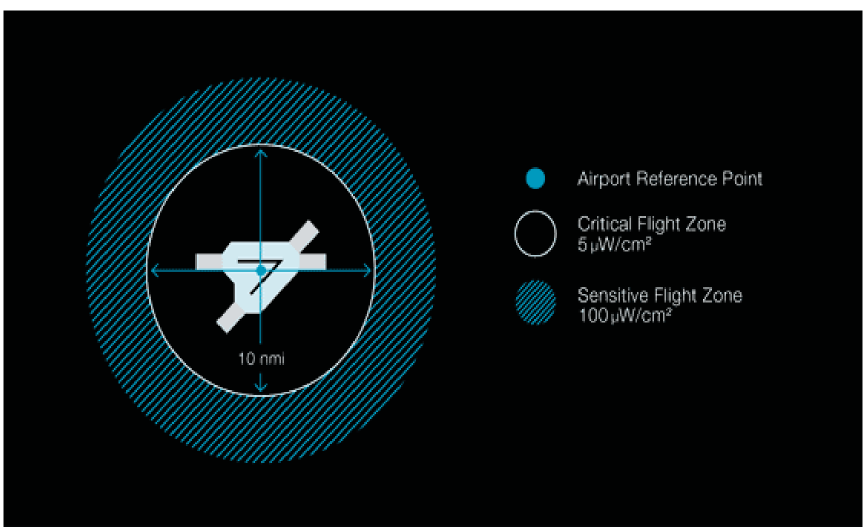


Figure 2 - The "critical flight zone" around an airport [11]

ii. Attack Frequency and Laser Color Intensity

Since 2005, laser attacks on aircraft have increased by nearly 1300%; this upward trend is still rising at alarming rates, as shown in Figure 3 [3]. Over the last two years, there have been nearly 7,500 reported attacks in total [4]. These attacks are not spread evenly, as specific airports tend to be the focus for laser illuminations. High-volume airports located in densely populated areas are more susceptible to attacks. For example, of the eleven laser attacks that take place each day nationwide, one takes place in the New York metropolitan area [2]. However, laser attacks are unpredictable events, and lower-volume airports should not discount the possibility of such attacks happening, as their effects can be detrimental.

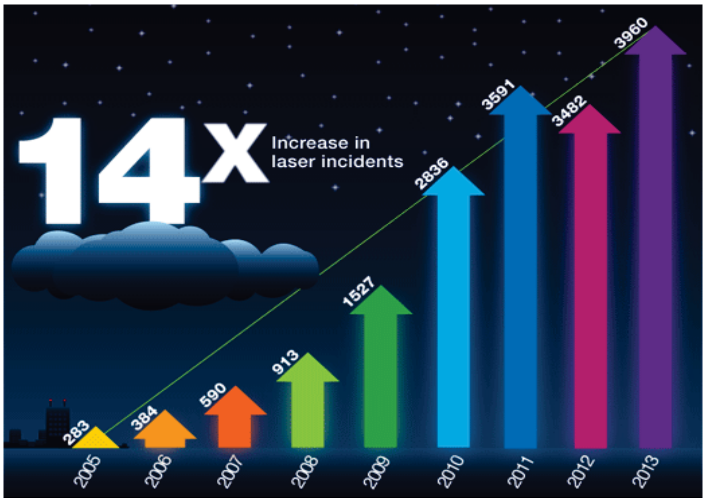


Figure 3 - The increase in domestic reported laser attacks over a nine-year period [6]

An overwhelming majority of illuminations use lasers with green wavelengths, as the human eye is most sensitive to that frequency [1]. From 2004-2008, around 88% of the recorded attacks corresponded to green lasers [1]. The same study indicated that 70% of the reported attacks occurred during the evening hours from 7:00 p.m. to 11:00 p.m. [1]. A laser attack is more apparent and dangerous to a pilot when it is contrasted by a nighttime environment. Nighttime laser illuminations cause massive amounts of glare, as portrayed in Figure 1, and may cause pilots to lose focus and control of their aircraft.

iii. FAA Safety Goals

The FAA's “Destination 2025” vision statement [5] provides a layout of the goals the agency has set for improving the aviation system in the United States. Foremost among these goals is the need to “move to the next level of safety,” a concept defined as “air travel [being] routine and uneventful for everyone involved.” One of the FAA’s primary safety goals from its Fiscal Year (FY) 2012 Portfolio of Goals is to reduce both the commercial carrier and general aviation fatality rates below the respective rates of 7.6 fatalities per 100 million passengers and 1.04 fatal accidents per 100,000 flight hours [6]. Evidently, these goals of improved safety and routine passage mean reducing air risks such as laser attacks and establishing clear solutions for what actions should take place if an attack occurs. The FAA is aware of laser attacks and has created a national Laser Safety Initiative which outlines the proper response to a laser illumination [7].

iv. Limiting Attacks and Attacks’ Effects

Attacking an aircraft with a laser was expressly criminalized by the FAA Modernization and Reform Act of 2012 [8], although prior to this the FAA had announced its intention to assess civil penalties [9] and individuals had been prosecuted for the offense under other statutes such as the United States Patriot Act. The federal penalty for performing such an attack is a fine of up to $250,000 and up to twenty years in prison [8]; local and state penalties vary by jurisdiction. Due to the nature of these crimes, it is often difficult to find and prosecute even repeat offenders. Out of the 7,500 attacks in the last two years, the FAA was only able to take enforcement action in 96 cases [4]. Most of these attacks are acts of mischief rather than terrorism, however, that does not remove the potential danger laser attacks may cause to the aircrew and, ultimately, passengers.

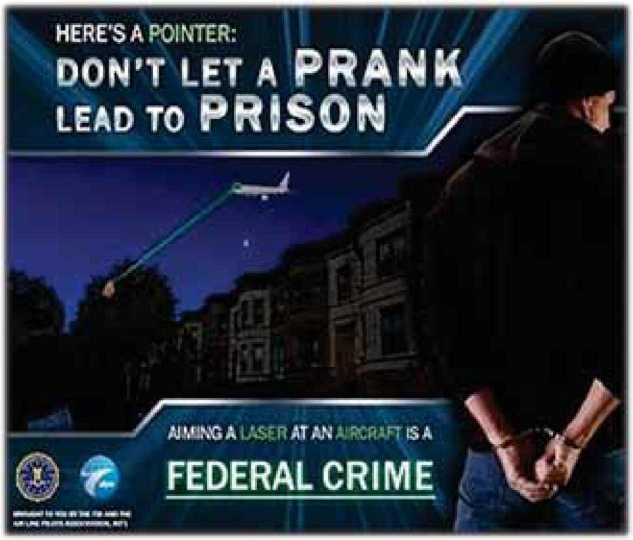


Figure 4 - An anti-laser attack public service announcement from the FAA, FBI, and Air Line Pilots Association [2]

The FBI, working in partnership with the FAA, drew attention to the severity of the problem through a series of marketing and judicial campaigns. On February 11, 2014, the FBI announced that the agency will be offering a $10,000 reward to anyone who comes forward with information that leads to the arrest and conviction of a person who intentionally shines a laser at an aircraft [2]. One such example of an anti-lasing campaign is shown in Figure 4.

The current safety procedure recommended by the FAA is a combination of aversion and reporting techniques. The FAA advises that the pilot use his or her arms to shield him or herself from the beam [7]. This helps protect the pilot from the physical damage of a laser beam, but does not greatly alleviate the startling effect that may be a greater danger when the pilot is inside the critical flight zone. The pilot is then encouraged to report the attack to Air Traffic Control (ATC), as prescribed by the FAA's Laser Safety Initiative [7].

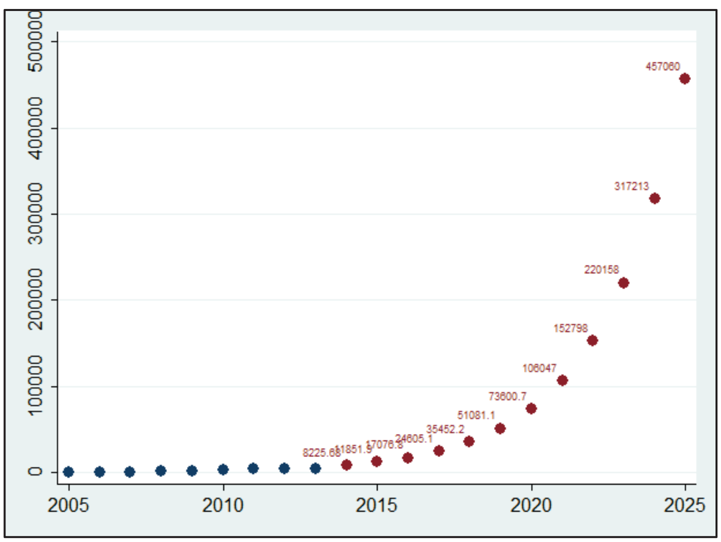


Figure 5 - An extrapolation of laser strike frequency into 2025 [3]

v. Problem Statement

The continual increase of laser attacks poses a severe risk to pilots, aircrew, and travelers.

Without a clear, effective solution to this problem, unnecessary safety risks will persist. Although there has yet to be a fatality or passenger injury linked to one of these attacks, the likelihood of such an incident occurring is steadily growing. As shown in Figure 5, if the current trend of laser strikes continues, there will be over 457,060 laser strikes per year by 2025. The design proposed herein will mitigate this hazard with a proactive and systematic solution to protect pilots and aviators from the harmful effects of laser illuminations.

II. Summary of Literature Review

i. FAA Safety and Goals

In 2011, the FAA released "Destination 2025," where it outlined future goals of the aviation community. One aspiration is to move to the next level of safety, as "safety is the FAA's top priority. We [the FAA] will transform the way we assure safety by expanding our safety culture to enhance standards and oversight. We will take action to manage risk by proactively identifying hazards and risk based on continuous analysis of data" [5].

Ensuring a seamless procedure during the most critical stages of flight: taxi, takeoff, and landing is an integral part of the safety initiative. Laser incidents are threats that require attention as they can affect all three critical stages. Laser pointers are used to cause disruptions by striking aircraft cockpits, causing injury, distractions, and/or loss of control. The FAA released a memorandum in 2011 stating that "directing a laser at an aircraft from the ground could constitute interference with a crewmember" [12]. These events are hazardous and may compromise a flight operation. A proactive approach to this problem should be taken to meet the FAA's goal stating that, "no accident-related fatalities occur on commercial service aircraft in the U.S" [5].

ii. General Protocol for Safety Hazards by the FAA

In its Safety Management Systems Manual, the FAA describes hazards related to safety in both the airport terminal and flight. In each instance, steps are provided for airport personnel and pilots; guidelines are specifically designed to reduce the potential for damage and personal injury so that all staff and patrons involved can be safe during operations [13]. Many of the safety requirements and risk prevention systems that are currently in place under the FAA's authority are influenced by the National Transport Safety Board (NTSB). The NTSB is responsible for reviewing the safety procedures in use by various transportation-related organizations in the United States [14].

iii. Threat of Laser Attacks

According to the FAA Risk Matrix, found within the Risk Management Handbook, an occasional and critical risk during flight is classified as a serious threat to safety [15]. Laser strikes are one such hazard that qualifies as occasional in frequency and critical in danger posed. The FAA Safety Management Systems Manual states that a high risk threat, such as laser strikes, must be "mitigated to an acceptable level of risk (medium or low)" [16]. As laser strikes become more common nationwide, the need for mitigation becomes greater [17]. Nationwide, reports of laser strikes are rising dramatically. The rates rose from 283 instances of laser attacks on aircraft in 2005 to 3,960 reports in 2013 [17], (see the prior Figure 3 for a more detailed breakdown of laser illuminations per year). Furthermore, the FBI predicts that the number of laser attacks will reach 4,000 this year [18]. Since the majority of laser strikes occur during landing and takeoff, the high frequency of these attacks inhibits the FAA goal of "maintain[ing] the rate of serious runway incursions at or below 20 per 1000 events" by 2018 [5].

The greatest danger of laser strikes occurs when the beam enters the cockpit during landing or takeoff, within the critical flight path of ten nautical miles around the runway area. The beam "can distract or disorient a pilot and cause temporary visual impairment," compromising a pilot's control of the aircraft [7]. Takeoff and landing are particularly dangerous portions of a flight's path as 52% of all accidents occur during these critical phases [19]. Laser strikes are at their peak effectiveness during those two phases and are further heightened by the low-light levels in a cockpit at night. Low light levels increase the two most prominent physiological effects of laser illuminations, startle and distraction. Startle and distraction can cause a pilot to misjudge his landing, improperly takeoff, or lose control of the aircraft. Pilots attacked by lasers have also reported severe glare, flash blindness (a persisting visual interference), and afterimages [7]. As the majority of laser strikes are directed towards commercial aircraft, hundreds of lives can be put at risk [20]. In order to comply with the goals and risk management processes of the FAA, the dangerous and frequent threat of laser strikes must be mitigated.

iv. Current FAA Response to Unauthorized Laser Illumination Events

Instances of unanticipated laser exposure are referred to as Unauthorized Laser Illumination Events. The FAA already has a robust system of regulations for public laser activity, which includes the designation of flight hazard zones that are specifically intended to avoid possible laser radiation from the ground. It has also established Local Laser Working Groups to assess the possible effects of laser activities on pilots [21]. For the laser events that are unanticipated, the FAA uses human error analysis to develop a set of protocol for pilots to follow in order to minimize the potential severity of the damage caused by the laser induced human error [13].

According to Advisory Circular 70-2A, pilots are advised to avoid “direct eye contact with the beam,” to shield their eyes “to the maximum extent possible consistent with aircraft safety,” and to immediately report incidents to ATC. The ATC will proceed to alert pilots in the immediate area, via broadcasts, warning them to remain on high alert or stay clear of the area where the initial laser event took place [7]. The mental preparation that pilots gain via such broadcasts has typically been found to reduce the “startle effect,” the most dangerous part of a laser event [22].

After such an event, pilots are required to fill out the FAA Laser Beam Exposure Questionnaire to record the exact details of the strike. Details include the crewmembers affected by the laser event, the direction and relative area the laser was coming from, the phase of flight the airplane was in, and the appearance of the laser itself [23]. Depending on the severity of the damage caused to the pilot he may go through a series of eye exams to assess the possible physical damage to his eyes. The Laser Injury Guidebook, created by Patrick J. Clark and John M. Gooch of the United States Air Force, outlines the standard operational procedure used to tend to pilots that have been damaged by laser attacks [24].

v. Current State of Laser Industry

While U.S. law restricts laser pointers based on electrical power, even among lasers of equivalent power the perceived strength of the beam by the human eye varies widely based on wavelength [25]. Lasers with a green wavelength of 500 to 550 nanometers appear up to 28 times brighter than red lasers of identical power [25]. Compounding this issue, green lasers have recently become more readily available as the price has significantly decreased [26]. Of laser illumination incidents reported in 2004 through 2008, green lasers accounted for 92% of incidents in which a color was identified [26].

vi. Existing Technologies

Compounds to effectively reduce transmission of green light in glass with a relatively small effect on light from other areas of the visible spectrum have existed since the 1940s [27]. Today, so-called "minus green" filters are readily available and in widespread use in the photography industry to limit green output from fluorescent sources, which have a green spike in their emission spectrum [28]. These filters, known to the industry as gels, are typically made of dyed polyester [28]. Such an approach is very economical as a 4'x25' roll of green-reducing gel is available for $130 [29].

III. Problem Solving Approach

i. Analyzing the Problem

Under the guidance of Professor Nixon and Professor Ziegler, project leader Matthew Stupak conducted extensive research related to current issues in the aviation industry. After weighing several options, Matthew decided to tackle the growing laser illumination problem. The FAA has already begun to recognize the significant growth of laser illuminations around the country as the number of incidents being reported has increased exponentially since 2005. Matthew formed a team of eight students who showed interest in addressing the problem. Before formally joining the team for the FAA Design Competition, team members were briefed about the specific challenges and the growing concerns related to laser illuminations.

ii. Team Responsibilities

Based on their individual skills and strengths, the eight students were divided into four two-person sub teams: Engineering and Graphics Team, Strategy and Ethics Team, Design Team, and Risk Assessment and Research Team. In addition to making many of the aesthetic decisions for the project, the Engineering and Graphics Team was primarily concerned with researching the background information related to the problem. The Design Team was responsible for researching the technical aspects related to laser light mitigation, as well designing the final proposal. The Risk Assessment Team analyzed the potential hazards and benefits of the final design choice and ensured that the solution fit within FAA regulations. The Strategies and Ethics Team was responsible for documenting every step of the problem-solving approach, as well as considering the ethical implications underlying the teams design choices.

iii. Design Choices

Figure 6 - Samuel Bravo presents the group's list of solutions

After the initial brainstorming, each sub team was assigned to research a particular area of literature related to the project. The Design Team researched FAA goals and proposed solutions, the Strategies and Ethics Team researched current solutions, the Risk Assessment Team researched the threat lasers pose to airport operations, and the Engineering and Graphics team researched alternative solutions to the issue. After compiling their findings, the team, as a whole, discussed the best way to handle the laser illumination problem.

Many solutions were initially proposed by team members, but ultimately their hard work culminated in the development of three different solutions to the problem: laser-protective glasses, laser-protective visors, and a laser-resistant spray-on application to be used on existing cockpit windows. Figure 6 shows Samuel Bravo of the design team discussing the advantages and disadvantages of each proposed solution to the problem. Figure 7 shows the list of pros and cons that were ultimately used to decide how to format the final proposal.

Proposed Alternative	Advantages	Disadvantages
Laser-protective Glasses	- Already available on the market - Inexpensive - Take up very little space - Requires no cockpit modifications - Easily accessed - Easily taken on and off mid-flight	- Pilots find them to be a hassle - Limits visible light transmission at all wavelengths - Inhibits vision of instruments in the cockpit
Laser-protective Visors	- Adjustable to laser direction - Will not interfere with reading instruments in the cockpit - There is sufficient space for installation near sun visors	- Requires installation - Incomplete coverage from incoming laser light - Requires reaction by pilot - Installing something inside of cockpit may require FAA approval
Laser-resistant Spray-on Application	- Could selectively block laser light - Requires no effort on the part of the pilot	- In prototypic stages - Requires modification to all cockpit windows - Would require review by the FAA and extensive testing

Figure 7 - The list of advantages and disadvantages for the three proposed solutions to laser illuminations

iv. Consultation of Industry Experts

On February 11th, 2014, the team traveled to the Binghamton Greater Airport (BGM) to discuss the viability of the proposed solutions with Carl Beardsley, Binghamton Aviation Commissioner, Charles Howe, an electrical engineer at McFarland Johnson Inc., and Doug Goodrich, CEO of Goodrich Aviation. Commissioner Beardsley advised that the group should avoid making any permanent modifications to aircraft, as it could take a long time for such drastic changes to be approved by the FAA. Charles Howe urged the group to consider the reduced visibility of runway lights that may be brought about by the use of laser-protective glasses or visors. Doug Goodrich, a pilot himself, recommended the use of glasses as it would be simple and cheap to implement onboard aircraft of all makes and sizes. Additionally, Doug Goodrich mentioned that

Figure 8 - Jack Fischer, Nur-al-din Harper, Lisa Frost, and Samuel Bravo consulting Doug Goodrich in the BGM Hangar

pilots would likely accept and adopt the proposed changes, as safety is always of the utmost concern to aircraft operators. The team's trip to the hangar can be seen in Figure 8.

The Design Team later consulted Dr. Wayne E. Jones, chairman of the Binghamton University Chemistry Department, and his research team about the development of their selectively laser-resistant spray-on application. They provided the team with information about the physics that made the spray possible and clarified that the spray was still being heavily tested. Ultimately, the Design Team ruled that it was not yet feasible to incorporate the spray into laser protection systems to be used by the aviation industry as there were too many current unknowns surrounding the product.

v. The Final Proposal

Based on research and professional consultations, the team determined that the best way to reduce the risk of laser illuminations is by implementing laser shields as either protective glasses or visors depending on the make of aircraft. On large commercial planes, the visors would be more appropriate as their larger size would cover a more significant portion of the cockpit window. Smaller non-commercial planes would benefit from protective glasses because of the limited space available and perhaps even funds to install a visor. The proposal also states that the use of both pieces of equipment would be added as part of the pilot's checklist in preparation for critical stages of flight.

A design review was presented to Commissioner Carl Beardsley, Charles Howe, and President Harvey Stenger of Binghamton University by Design Team members Samuel Bravo and Jack Fischer. The final design received praise for avoiding a one-size-fits-all approach to the growing laser strike problem. Additionally, Commissioner Beardsley commented that the proposal was highly feasible, as it avoided much of the "red tape" that would have come along with making permanent modifications to aircraft. Figure 9 depicts Jack Fischer's demonstration of laser light reduction during the design review.

vi. Safety and Maintenance

The final proposal falls directly in line with many FAA goals related to runway incursions, as it would reduce the risk involved with laser illuminations harming, distracting, or even blinding pilots during critical stages of flight. By shielding pilots from the blinding light of laser illuminations, the incorporation of the laser shield systems into the pilot's checklist could potentially prevent hazardous complications during take-off and landing on the runway. Due to the durable nature of the polyester film used in the laser shields, maintenance of the systems should be infrequent. Additionally, neither fixture would be permanently fixed to the cockpit's interior, making the replacement of ineffective laser shields very simple.

Figure 9 - Jack Fischer demonstrates the film that reduces the potency of green laser light to President Harvey Stenger

vii. Conclusions

With collaboration between sub-teams as well as feedback and advice from industry experts, the team was able to weigh several options against one another and properly evaluate the effectiveness of each element of the proposal. Overall, the problem solving approach led the team to a flexible, practical solution to the rising number of laser illuminations.

IV. Technical Aspects Addressed

Light is electromagnetic radiation that behaves as a wave. Many different wavelengths of electromagnetic radiation exist, yet not all are visible to humans. For example, ultraviolet light and radio waves are not visible to the eye as their respective wavelengths fall outside of the eye's perceptible range [30].

The range of wavelengths that can be perceived by the human eye is relatively small. This range is commonly referred to as the visible spectrum [30]. Figure 10 illustrates how the eye perceives different wavelengths of radiation in the visible spectrum.

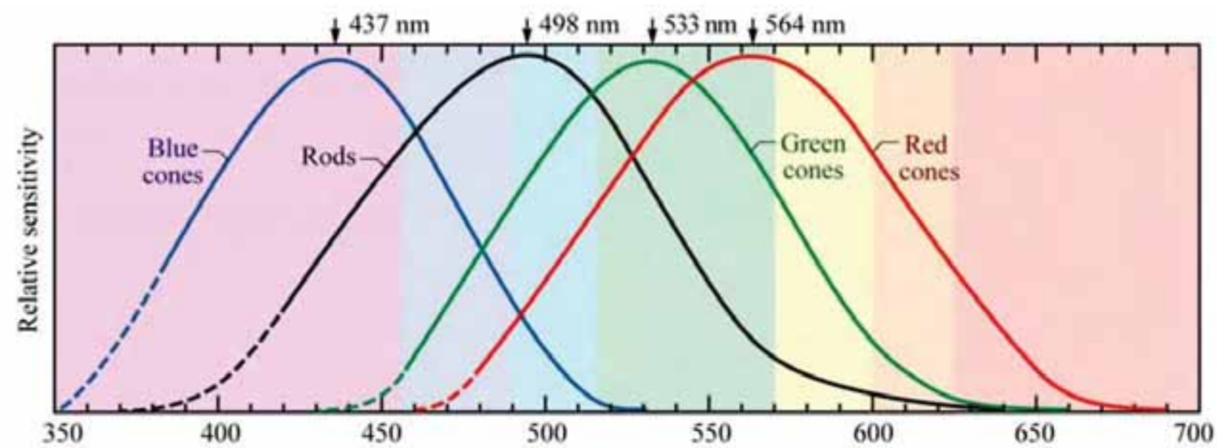


Figure 10 – Colors as perceived by the human eye across different wavelengths [31]

Laser stands for Light Amplification by Stimulated Emission of Radiation. Lasers emit light in a physically narrow beam, which allows them to be perceived more intensely and over longer distances [30]. This focusing can cause the output of lasers to be orders of magnitude more intense than natural light sources [30]. Another factor that distinguishes laser light is its narrow spectrum of wavelengths emitted [32]. Light from, for example, lighting fixtures or the sun, contain a wide spread of wavelengths that when perceived together, do not appear to have a particular color [32]. However, the conglomerate nature of non-laser light can be observed by using a prism to separate individual wavelengths of light from one another. In rainbows, water droplets in the sky act as prisms by separating the different colors of sunlight into distinct bands of color [32]. However, laser light is emitted across a very limited range. This causes laser output to be perceived as a single color, dependent on the wavelength of the radiation emitted.

Most consumer green lasers have a wavelength of 532 nanometers, as this wavelength is very close to the peak visibility of green in human eyes, as shown in Figure 10. The top 20 laser pointers available for purchase on retail site Amazon.com all specified a wavelength of 532 nanometers (nm). Red lasers are similarly uniform; where the top 20 lasers listed have a wavelength of 550 nm.

As previously discussed, the vast majority of laser attacks on pilots employ green lasers. Green lasers account for 88% of all reported attacks in 2004-2008 in which a color was identified, while red lasers account for only 9% [33]. Together, they account for 97% of all laser strikes. This unbalanced distribution used in laser attacks coincides with the sensitivity of the human eye. Figure 11 shows the relative sensitivity of the human eye to various wavelengths of visible light, where green light at 555nm is a disproportionately sensitive area.

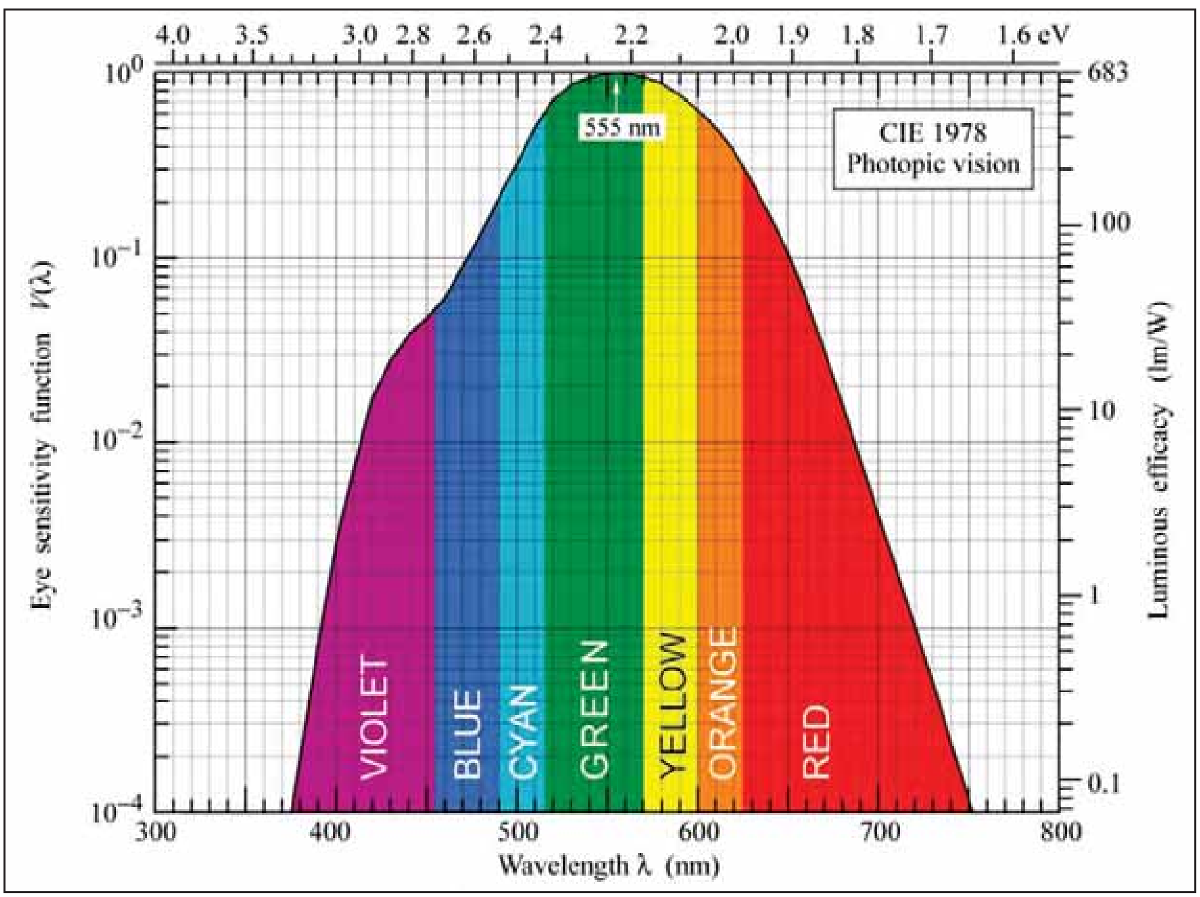


Figure 11 - Graph showing eye sensitivity to different wavelengths [31]

This sensitivity to green could be the root cause of the common use of green lasers; for example, there may be many more attempted laser strikes on pilots with red lasers than are recorded, but because they are harder to perceive, they may go unnoticed, while pilots largely only report attacks involving the highly visible green lasers.

If the data on sensitivity is combined with the known distribution of laser attacks, it is apparent that the greatest danger to pilots is centered at green wavelengths. Figure 12 shows this intersection between relative eye sensitivity (highlighted in purple) and frequency of attacks across the visible spectrum (shown in green and red).

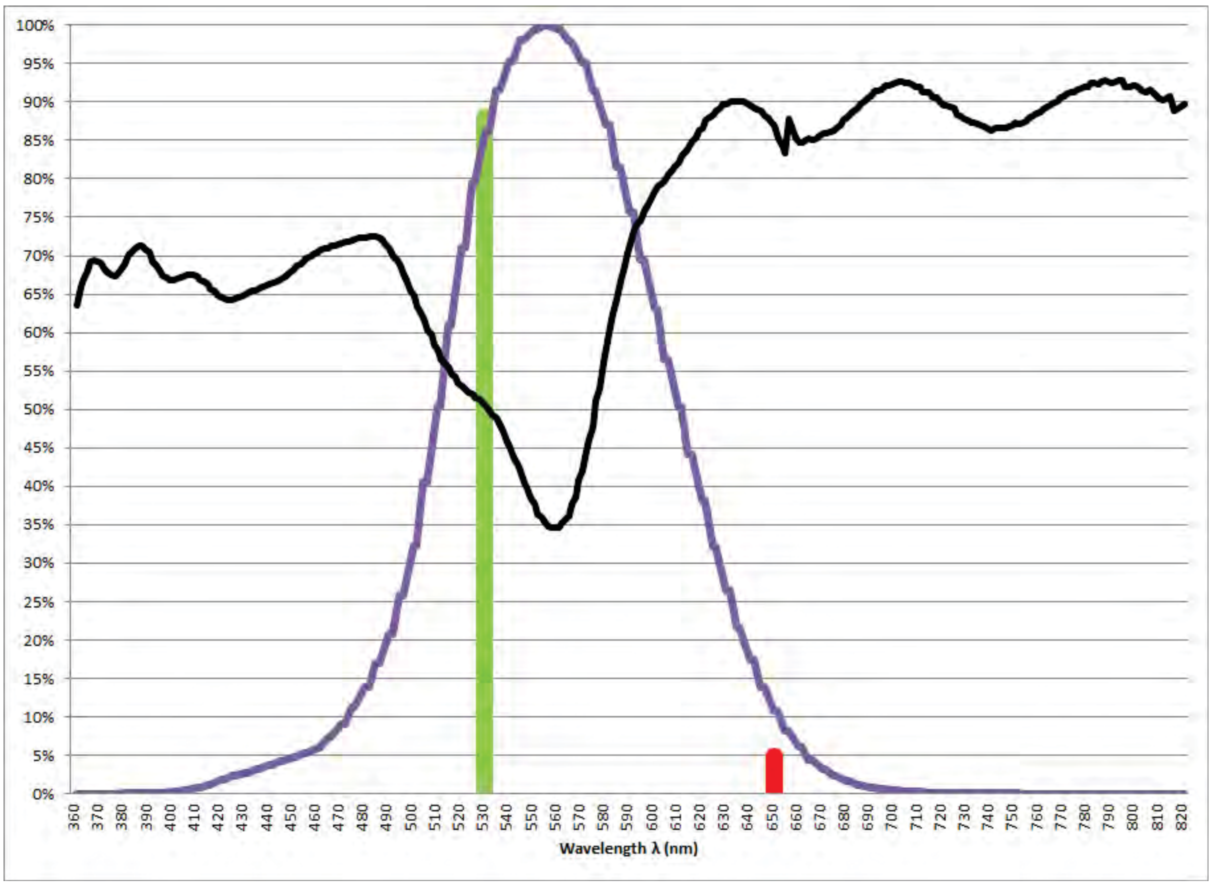
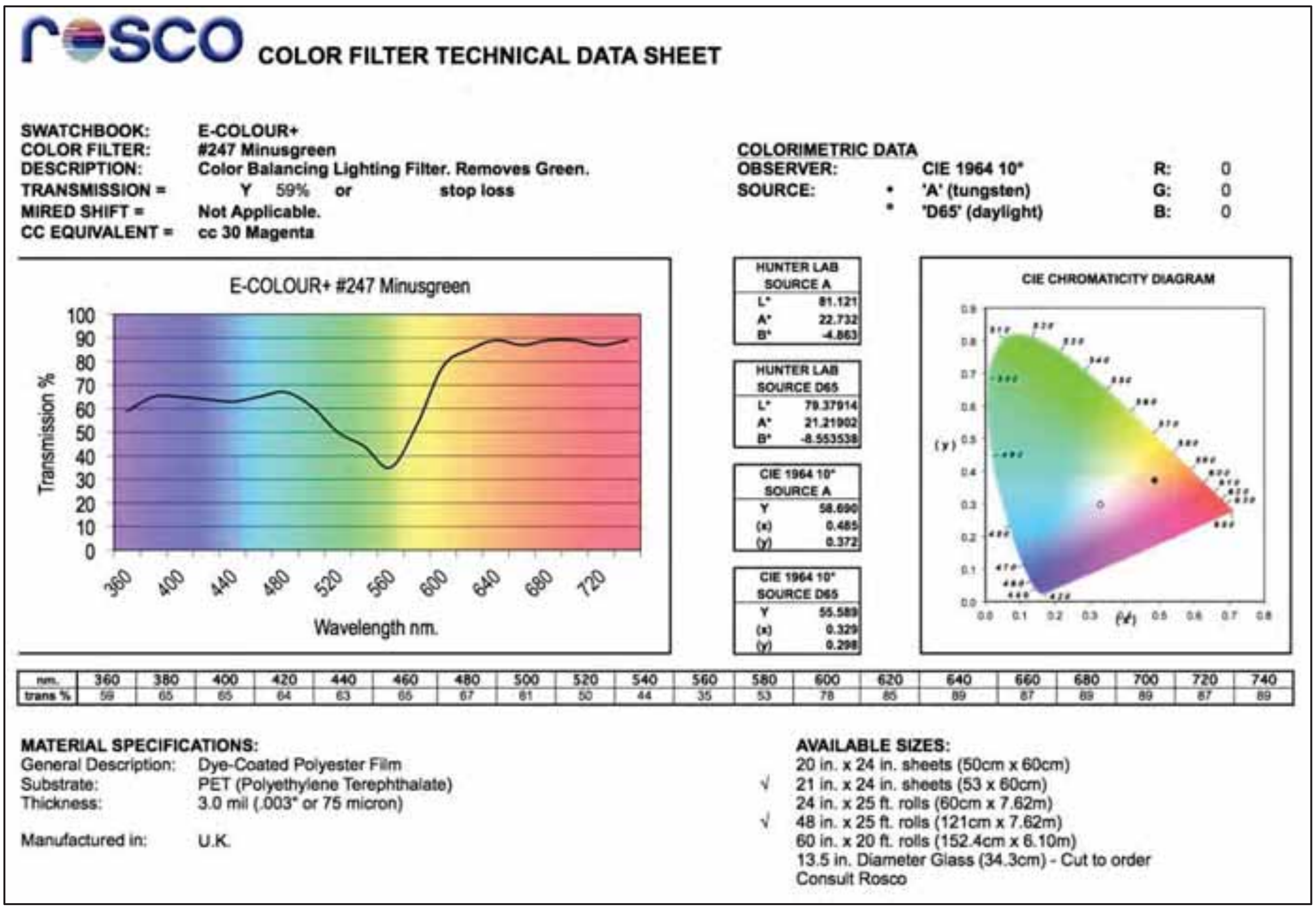


Figure 12 - Frequency of laser attacks are shown in their respective wavelengths [33] (for red and green lasers). Relative human eye sensitivity is emphasized in purple [31]. The polyester film's transmission of light is shown in black

An ideal solution to laser attacks would significantly reduce or eliminate light in the 532 nm range. While pinpointing a precise wavelength is impractical, the photography industry has developed materials to significantly reduce transmission of undesired wavelengths while leaving the remainder of the visible spectrum largely unaffected. Figure 13 shows a data sheet from a photography equipment manufacturer for a polyester film designed to reduce light transmission in the green range. Note that the transmission of light is under 50% for the 520-580 nm range.


COLOR FILTER TECHNICAL DATA SHEET

SWATCHBOOK: E-COLOUR+
COLOR FILTER: #247 Minusgreen
DESCRIPTION: Color Balancing Lighting Filter. Removes Green.
TRANSMISSION = Y 59% or stop loss
MIRED SHIFT = Not Applicable.
CC EQUIVALENT = cc 30 Magenta

COLORIMETRIC DATA
OBSERVER: CIE 1964 10° R: 0
SOURCE: • 'A' (tungsten) G: 0
• 'D65' (daylight) B: 0

HUNTER LAB SOURCE A: L* 81.121, A* 22.732, B* -4.863
HUNTER LAB SOURCE D65: L* 79.37914, A* 21.21902, B* -8.553538
CIE 1964 10° SOURCE A: Y 58.690, (x) 0.485, (y) 0.372
CIE 1964 10° SOURCE D65: Y 55.589, (x) 0.329, (y) 0.298

nm.	360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	720	740
trans %	59	65	65	64	63	65	67	61	50	44	35	53	78	85	89	87	89	89	87	89

MATERIAL SPECIFICATIONS:
General Description: Dye-Coated Polyester Film
Substrate: PET (Polyethylene Terephthalate)
Thickness: 3.0 mil (.003" or 75 micron)
Manufactured in: U.K.

AVAILABLE SIZES:
20 in. x 24 in. sheets (50cm x 60cm)
√ 21 in. x 24 in. sheets (53 x 60cm)
24 in. x 25 ft. rolls (60cm x 7.62m)
√ 48 in. x 25 ft. rolls (121cm x 7.62m)
60 in. x 20 ft. rolls (152.4cm x 6.10m)
13.5 in. Diameter Glass (34.3cm) - Cut to order
Consult Rosco

Figure 13 - Polyester film manufacturer's data sheet [34]

A full diode array was used to show how the film prevents the transmission of green wavelengths. A full diode array evaluates the nature of a material's light transmission at different wavelengths. Figure 12 shows the results of this test. The majority of the visible spectrum is transmitted without significant interference; however, light in the green area is significantly reduced.

Figure 12 shows the transmission of the film juxtaposed with the frequency and wavelength of laser attacks and sensitivity of the human eye, which shows the solution to the danger caused by the attack frequency combined with human sensitivity to exposure. At precisely 532 nm, the most common wavelength of green lasers, 50.3% of radiation is blocked from entering the pilots' eyes.

Figure 14 - The area of vision most important to a pilot during a laser attack is highlighted in green [35]

The same polyester film can be applied in the cockpit for protection against laser attacks. First, it may be applied as a laser shield: a visor that flips down to cover the main windshield.

Figure 15 - The location of the visor, shown in red, is designed to cover the area highlighted in Figure 14 [35]

Laser attacks are most dangerous during the critical stages of flight: takeoff and landing. In those stages, pilots need to be able to see the runway directly in front of them, as illustrated in Figure 14. The visor flips down far enough to cover the lower center of the main windshield. Figure 15 shows an approximation of the area that would be covered by a visor implemented in the cockpit. If a laser attack comes in from a different angle, it will not be such a distraction to the pilot as it is not directly in the pilot's line of sight. For this reason, the team has decided not to focus on visors that cover the side windows.

The laser shield's design consists of a hinged two-part visor that looks similar to the sun visors currently used in aviation. The laser shield is set up on the roof, behind the sun visor. However, it faces the opposite direction, and does not interfere with any sun visor design, as shown in Figure 16.

The laser shield can be created by current sun visor manufacturers with minor changes in the film design. The polyester film can be applied over a transparent base that provides necessary support to the structure of the laser shield.

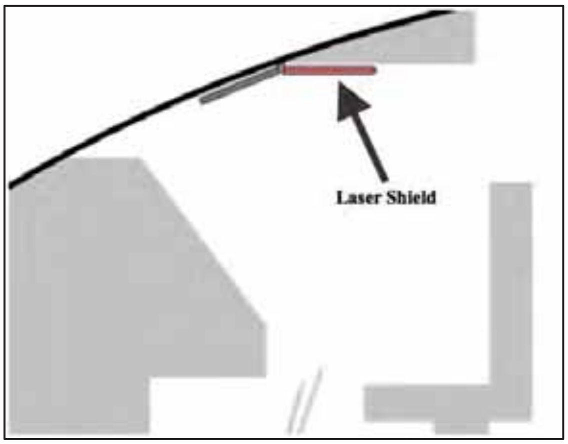


Figure 16 - Laser shield's position in the cockpit

In the event of a laser attack, a pilot may reach overhead and lower the laser shield. This maneuver is an intuitive and natural reaction, as a pilot would lower a sun visor in a similar way in response to sun glare.

However, all laser attacks take place from the ground, rather than from above, so the area of the windshield that needs protecting is at a lower angle than most sun visors reach. Therefore, a two-part visor design for the laser shield was designed. The shield consists of two parts of equal size, joined together along the middle by hinges, as shown in Figure 17. The lower visor has a safety mechanism that fastens onto the upper visor when folded, so that it does not move around. Once the pilot lowers the whole visor, he may unfold the lower portion by simply letting it loose and lowering it. The lower visor will then stay in place at the unfolded position, so that the bottom portion does not swing around, by a similar fastening mechanism in the hinges. As soon as the laser attack is no longer a threat, the pilot may once again fold the laser shield back up to its original position.

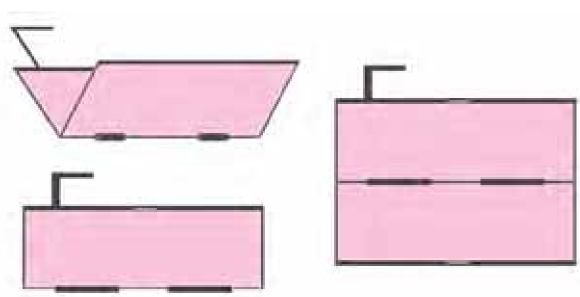


Figure 17 - Laser shield design, shown in open and closed positions

It is very difficult for a person to steadily hit a moving target with a laser pointer from a great distance. As a result, pilots will first see a flash of green pass by quickly followed by another surge a few seconds later. The pattern continues similarly; instead of a continuous laser strike, the pilot is more likely to see sporadic and sudden bursts of light, fixed for a few seconds and then disappearing while the laser gets repositioned. Due to this, a visor is an excellent solution for a laser strike. The instability of the laser's direction gives the pilot enough time to lower the laser shield while the laser pointer is being repositioned. In fact, the deployment time of the sun visor is merely a few seconds.

The laser shield outlined above may not be appropriate for all types of aircraft. From conversations with Doug Goodrich, it was concluded that aircraft with smaller cockpits will find it inconvenient to implement the laser shield. This is both due to both financial burden and practical issues with implementations in non-commercial aircraft. While laser shields should be implemented in larger and all commercial aircraft, an additional solution would also be beneficial to smaller aircraft. The polyester film can also be implemented as protective eye-glasses for the pilot's use. The eye-glasses, similar to sun-glasses are useful to protect a pilot's full range of vision in all types of aircraft.

Figure 18 - The protective eye-glasses will be stowed behind the clipboard [36]

As the cockpit is a very space-efficient environment, the protective eye-glasses must be placed somewhere where they are easily accessible, yet do not interfere with the controls or instruments. After consulting with Doug Goodrich, the team decided that the best location for the eye-glasses would be behind the clipboard, as shown in Figure 18.

A clip, such as the one in Figure 19, is used to secure the eye-glasses in place, similar to those used in automobiles. The clip is positioned above and slightly behind the clipboard to avoid intrusion in the pilot's normal activities. The protective eye-glasses are thus safely stored, accessible, and do not interfere with regular operations.

Figure 19 - Existing clip to hold sun-glasses [37]

An integral part of the proposed solution is a simple and effective strategy that pilots may follow. A significant issue during laser strikes is that pilots do not have standard instructions on how to protect themselves from the attack. Therefore, a three-part strategy to deal with laser incidents is proposed: Protection, Communication, and Prevention.

i. Protection

Laser attacks are universally unexpected. There is no way for a pilot to know pre-emptively when the first laser attack will take place. Pilots should be educated to put on the protective eye-glasses the moment they recognize they are in a laser strike. They should also lower the laser shield if one is available.

According to consultations with Kenneth Marzolf, an experienced pilot, "It is crucial for a pilot to expect a standard solution to any problem. Wherever the eye-glasses are placed, it should be uniform across all aircraft. If pilots have a proper procedure in place, it does not interfere with the landing or takeoff process." Therefore, the FAA should educate pilots on one standard response to an unexpected laser event; creating an intuitive reaction for all pilots during a strike.

The FAA Advisory Circular 70-2A currently indicates what to do in the event of a laser attack. Section 7, aircrew mitigation procedures, states the current approach for pilot's protection,

> "... In the event aircrews are unexpectedly exposed to laser illumination, direct eye contact with the beam should be avoided, and eyes should be shielded to the maximum extent possible consistent with aircraft contract and safety. ATC understands that, under these circumstances, aircrews may regard the event as an in-flight emergency and may take evasive action to avoid further exposure to the laser illumination. … Research is underway by Government and private industry focusing on technological solutions for enhancing aircrew safety during laser incidents. Additional mitigation procedures will be issued as they become available." [38]

The laser shield and protective eye-glasses are technological, yet simple, solution to laser attacks, and should be implemented as new mitigation procedures in the Advisory Circular.

ii. Communication

Once a laser attack has taken place, the pilot should contact the airport and inform it of the situation. Of the three part strategy, this component is the only one that is currently implemented; the Advisory Circular 70-2A states that the pilot should contact the ATC and report the incident [38].

iii. Prevention

After an incident has been reported, the ATC alerts all other surrounding aircraft concerning the laser attack. The airport is then considered a laser active zone, and pilots are required to lower their laser shields while within ten nautical miles of the location, as this is the area where laser beams may interfere with critical flight operations [39]. ATC will then indicate to pilots when the attack has subsided and an "all clear" is given. This approach will help prevent further consequences during the laser strike. The FAA should implement this three part solution of Protection, Communication, and Prevention within an Advisory Circular. Figure 20 shows a mockup of an Advisory Circular with these procedures specified. This strategy will ultimately mitigate the dangers posed by laser attacks.

U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: Regulation of Laser Illumination of Aircraft | **Date:** March 26, 2014 | **Initiated by:** AJR-2 | **AC No:** 70-2B | **Change:**

7. AIRCREW MITIGATION PROCEDURES

a. Protection during an initial laser attack

- In the event that a laser attack is recognized, pilots are to put on the protective eye-glasses located behind the clipboard. If a laser shield are available in the aircraft, pilots are also to lower the laser shield to its open position.

b. Communication to Airport Traffic Control immediately following laser attack

- As soon as possible, following an incident, pilots should report it to the appropriate ATC facility in accordance with the guidance provided by this AC. Forward as much information as available. Expeditious reporting will assist law enforcement in locating the source of the laser transmission.

c. Preventative measures implemented while airport is a laser active zone

- After an incident has been reported, ATC alerts all other surrounding aircraft concerning the laser attack. The airport is now considered a laser active zone, and pilots are required to lower their laser shields while within 10 nautical miles of the location.

- ATC will indicate to pilots when the attack has subsided.

Figure 20 - Mockup of an Advisory Circular outlining the new aircrew mitigation procedures following the Protection, Communication, and Prevention strategies

V. Safety and Risk Assessment

The Integrated Product Development System in the FAA System Safety Handbook provides a method for assessing the risk of new technology before it is implemented. The system calls for a close examination of potential hazards the new technology may pose through defects or human errors. The Hazard Tracking portion of the system calls for investigation and tracking of any new technology that is deemed high or medium in risk [40].

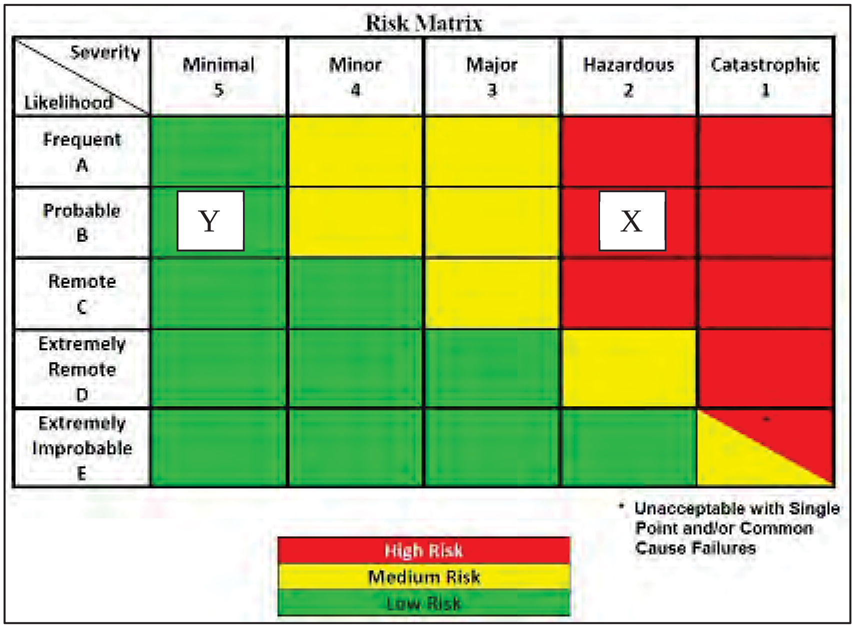


Figure 21 - Predictive Risk Matrix [16]

To understand quantified risk, the FAA uses the risk matrix found within Safety Management Systems Manual. The matrix, shown in Figure 21, ranks risk based on likelihood and severity [16]. To avoid any tracking or investigation, new technology must be proven to be of low risk. Risk reduction, one of two options outlined FAA Advisory Circular 150/5200 for risk management, is the best method for the design [41]. In adherence to risk reduction, the design strives to reduce the magnitude of the consequences of the accepted risks. The goal of the assessment is to move the accepted risk of laser attacks from Hazardous [X] to Minimal [Y], outlined on Figure 21, within the Probable likelihood of the attack.

i. Blocking of Green Runway Threshold Lights

The FAA Advisory Circular 150/5345-46D mandates pure green unidirectional lights (L-850E) for the runway threshold. The threshold lights outline the edges of runways during periods of darkness or restricted visibility conditions in inclement weather [42]. A potential risk associated with the laser mitigation design is the decreased visibility of these green lights. The bidirectional runway lights will not be blocked by the design. These lights are green-red and green-yellow [42]. Their wavelengths are outside of the spectrum blocked by the laser film. The pure green threshold lights will be blocked by the laser film, but not completely. The Advisory Circular mandates that L-850E green threshold lights have a minimum intensity of 5000 candelas. These high intensity green lights will remain visible even after 50% filtering. Amidst the filtering, these green lights will appear as bright as a regular red precision IFR lights (L-862E) [42]. Furthermore, pilots will still have the extremely intense white runway lights of 10000 candelas for guidance [42]. These lights will barely be filtered. To ensure absolutely safe operations, the green lights can be further intensified to the 10000 candelas of the white lights. At this level, the threshold lights will be fully visible even after filtration.

ii. Blocking of Interior Green Cockpit Lights

The protective glasses in the design will filter any pure green lights on the cockpit dashboard. The visor will have no effect on the interior lights, as it is positioned over the windshield. Most modern cockpits do not have pure-green lights on the dashboard because the wavelength of these lights compromises the safety of pilots' eyes [43]. Peak retina sensitivity occurs at a wavelength of 500nm, a green color [43]. After World War II, a literature review performed by the United States Military found that red and white lights in cockpits lead to the best visual performance [44]. Red and white do not interfere with eyesight as much as green light [43]. However, some aircraft, like the recreational aircraft with digital displays in the Goodrich Aviation hangar, still have pure-green lights outlining buttons on the dashboard. These lights have a sufficient intensity at a close range to penetrate the film. Furthermore, these lights are labeled in white text that was clearly readable through the film. To mitigate risk as much as possible, any pure-green buttons in airplane cockpits should be clearly marked by a different color.

iii. Conclusion

The proposed design for laser mitigation has reasonably safe accepted risks as it duly addresses the two potential risks it faces. The design lowers the severity of a laser strike to Minimal while posing no inherent risks itself. The green threshold lights and green cockpit lights will remain usable even when the design is in operation. With the design proposed, this system of protective eyeglasses and laser shields will reduce the risk of incoming laser attacks while introducing no internal risk. The new point in the risk matrix, [Y], is of low risk which is acceptable according to Advisory Circular 150/5200.

VI. Projected Impacts

i. Destination 2025

The document "Destination 2025" states, "The Federal Aviation Administration's mission is to provide the safest, most efficient aviation system in the world" [5]. As technology evolves, the FAA will need to implement new solutions to safety hazards that have not existed in the past. Laser strikes are new threats, and thus they require a new solution. The laser shield and protective eye-glasses solution is one way in which the FAA may "take action to manage risk by proactively identifying hazards and risk based on continuous analysis of data," which outlines the concept of "Moving to the Next Level of Safety," one of the five aspirations given in Destination 2025 [5].

The FAA seeks to reduce aviation risk "through all phases of flight (gate-to-gate)" [5]. The laser shield and protective eye-glasses will ensure pilot's safety, and thus the safety of the whole aircraft, in the event of a laser incident during the critical stages of flight. Instructing pilots to the new procedures during a laser attack is one example of meeting the goal to “strengthen and improve… training, procedures… to reduce the risk of accidents from all causes in all phases of operation” [5]. As laser strikes become more frequent in the future, implementing these safety solutions are necessary to meet the FAA's goal in reaching the performance metric of less than 20 serious runway incursions per 1000 events by 2018 [5].

ii. Commercial Potential

The laser shield and protective eye-glasses solution can easily be implemented commercially as the equipment for manufacturing sun visors or eye-glasses already exists. With small changes, the eye-glasses and visors can be produced in large quantities needed by the aviation industry.

One manufacturer already produces the base material for visors at an estimated price of $220 for two frames. All that is needed is to change the visor itself from the sun-blocking material to the minus-green polyester film. Since the polyester film is very thin, one approach would be to cover a transparent piece of plexi-glass with the film to provide support.

It is similarly easy to implement the protective eye-glasses. Once frames are purchased, the same approach as above may be taken to create lenses based on the polyester film. Since the placement of the protective eye-glasses in a convenient location within the cockpit is essential to the design, the support system must also be manufactured. Currently, there are sun-glasses clips of many shapes and sizes that can function for this need. They work by being attached to a car’s visor or pocket, so that the driver can have easy access to their sun-glasses if necessary. Some of these clip designs will be appropriate for placing the protective eye-glasses over the pilot’s clipboard in the cockpit. The team investigated the different types of clip designs and decided to go with models that are both appropriate in size and ease-of-use within a cockpit.

iii. Financial Analysis

Each airline will fund implementation of the laser preventive solutions in their aircraft. It should be noted that in the cases of larger airlines, implementing the system in bulk will likely reduce the per-unit costs of the various components.

Item	Cost	Quantity	Total
Sun Visor Frames	$220 / 2	4	$440
Eye-glasses Frames	$10 / 2	2	$10
Eye-glasses Clip	$5	2	$10
Polyester Film	$1.30 / Square Foot	4 Square Feet	$5.20
Labor	$55 / hour	1 hour	$55
		Total Cost per Installation:	**$520**

Figure 22 – Breakdown of total costs to install and manufacture a laser visor including eyeglasses

By calculating the price of two sun visors ($358) [45] minus the price of their respective lenses ($138) [46], the cost of two visor frames is approximately at $220. For installing the laser shields in one cockpit, four frames will be needed totaling $440. The cost of frames for the protective eye-glasses can be under $10 for two pairs [47]. A clip to mount the protective eye-glasses costs $5 [48], hence the two pairs needed for installation will cost $10. The cost of labor is $55 an hour and the visor can be fully installed during that hour of time. The polyester film costs $1.30 per square foot [29] and approximately four square feet will be used for one installation, bringing the price of polyester film per installation to $5.20. Thus, the cost of installation is approximately $520 per aircraft, see Figure 22 for a complete cost breakdown.

As shown previously in Figure 5, the team developed a model to predict future laser attacks based on existing trends. Of those attacks, about 73% are anticipated to be on commercial aircraft [26]. Of these laser attacks, approximately 1.6% caused injury or pain to the pilot [7]. According to the team’s conversations with Commissioner Beardsley, in the case of an incapacitated or injured pilot, there may be a ripple effect of flights as they are forced to be cancelled. For the purposes of this analysis, the model assumes that an injured pilot results in only one cancelled flight, although in reality the consequences are much greater, where rescheduling and time conflicts have to be taken into consideration.

While data for the direct cost to airlines of a cancelled flight is not available, CNN published data on revenue lost by JetBlue due to cancellations from a storm; cancelling a flight may cost an airline approximately $25,000 [49], while the overall economic cost to passengers, airports etc. is approximately $50,000 [50].

The total number of aircraft in the U.S. commercial fleet, including regional carriers, is estimated to be approximately 7,024 by the FAA, which has been steadily decreasing [51]. While some aircraft will be replaced, the cost of installation on a new aircraft during manufacturing is negligible with respect to the cost of an entire aircraft, which ranges anywhere from $50 to $300 million. For this reason, the most appropriate way to calculate an approximate cost of implementing this solution for the entire fleet is to focus on existing aircraft, as the largest cost will, by far, be upfront.

The laser shield and protective eye-glasses solution requires very little maintenance. Since it is on the inside of the cockpit, the material is not subject to weather changes or harsh conditions.

The Net Present Value (NPV), or value of an investment in terms of the present value of money, will be approximately $341,566,580 to airlines by the year 2025, as shown in Figure 24 and in bold in Figure 23. Given an initial cost of installing the solution on the U.S. commercial fleet of $3,652,480, the Return on Investment (ROI), or percentage of an investment that is produced as profits or savings, will be approximately 9,351% by the year 2025. Airlines will break-even when they have initially recovered the full cost of their investment, which is projected to occur no more than two years after implementation, as shown in Airline Cumulative ROI in Figure 23. The Total Costs of Ownership, an estimate used to show the combination of costs of implementing a system, includes only the upfront cost of installation, as there are no inbuilt recurring costs.

Year	Projected Total Laser Attacks	Attacks on Commercial Flights Causing Pain/Injuries (1.6%)	**Airlines'** Annual Cost of Cancellations	**Airline** Cumulative ROI	**Airline** Cumulative ROI, Present Values	**Economy's** Annual Cost of Cancellations	**Economy** Cumulative Savings	**Economy** Cumulative Savings, Present Values
2014	8226	96	$ 2,401,899	$ (3,652,480)	$ (3,652,480)	$ 4,803,797	$ (3,652,480)	$ (3,652,480)
2015	11852	138	$ 3,460,755	$ (191,725)	$(187,966)	$ 6,921,510	$ 3,269,030	$3,204,931
2016	17077	199	$ 4,986,426	$ 4,794,700	$4,608,516	$ 9,972,851	$ 13,241,881	$12,727,682
2017	24605	287	$ 7,184,689	$ 11,979,390	$11,288,446	$ 14,369,378	$ 27,611,259	$26,018,706
2018	35452	414	$ 10,352,042	$ 22,331,432	$20,630,791	$ 20,704,085	$ 48,315,344	$44,635,910
2019	51081	597	$ 14,915,681	$ 37,247,113	$33,735,858	$ 29,831,362	$ 78,146,706	$70,779,880
2020	73601	860	$ 21,491,404	$ 58,738,518	$52,158,123	$ 42,982,809	$ 121,129,515	$107,559,543
2021	106047	1239	$ 30,965,724	$ 89,704,242	$78,092,941	$ 61,931,448	$ 183,060,963	$159,365,585
2022	152798	1785	$ 44,617,016	$134,321,258	$114,641,900	$ 89,234,032	$ 272,294,995	$232,401,157
2023	220158	2571	$ 64,286,136	$198,607,394	$166,185,782	$ 128,572,272	$ 400,867,267	$335,427,797
2024	317213	3705	$ 92,626,196	$291,233,590	$238,912,980	$ 185,252,392	$ 586,119,659	$480,822,266
2025	457060	5338	$ 133,461,520	$424,695,110	**$341,566,580**	$ 266,923,040	$ 853,042,699	**$686,070,714**

Figure 23 - Financial Analysis of cost of solution over a ten year period

Based on the above data, it is clear that the benefits over a ten-year lifespan, $341,566,580, for the laser shield and preventative eye-glasses solution far outweigh the initial cost of $3,652,480 ($520 per aircraft). Therefore, this solution is not only technologically viable, but economical.

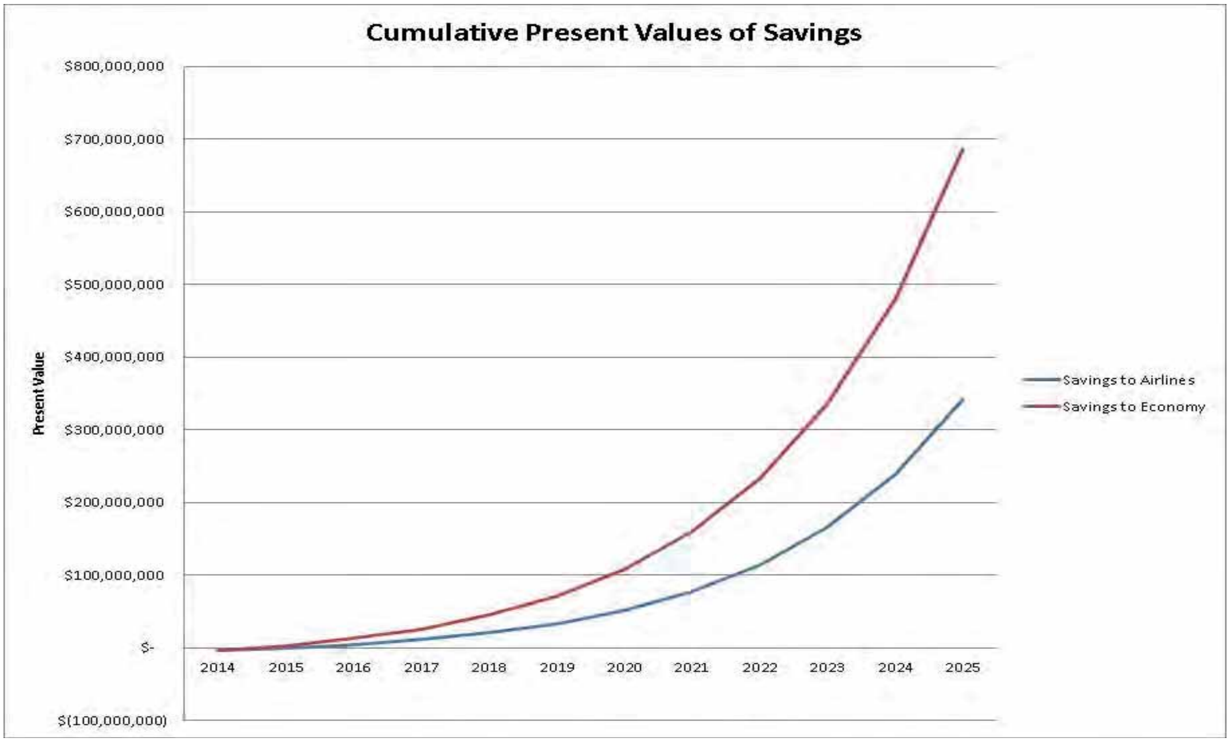


Figure 24 - Cumulative present values of the savings to both airlines and the economy respectively. The red line represents the savings to the economy whereas the blue line represents the savings to airlines

VII. Interactions with Airport Operators

During the course of the project's development, students gained meaningful perspectives on their design choices by contacting a number professionals with experience related to aircraft operations and chemical engineering. The team also contacted several professional pilots in order to get a firsthand perspective of an operator's reaction to changes stipulated in the proposal. Each provided personal input to the Design Team related to the potential dangers of laser attacks as well as the accessibility of laser mitigation tools in the cockpit. They also clarified certain standards of communication used by the American aviation industry. A more complete description of each industry expert can be found in Figure 25.

Contact Name	Affiliated Organization	Position	Discussion Topic	Email Address
Carl Beardsley	BGM	Commissioner of Aviation	Feasibility of adding proposal to pilots' checklists	cbeardsley@co.broome.ny.us
Jake Carnevale	Spirit Airlines	Commercial Pilot	Placement of glasses/visor in cockpit	jake.carnevale@gmail.com
Doug Goodrich	Goodrich Aviation	President and Flight Instructor at Goodrich Aviation	Pilot's perspective on use of glasses or visor	doug@goodrichaviation.com
Charles Howe	McFarland Johnson, Inc.	Electrical Engineer	Presence of green lights on runway	chowe@mjinc.com
Wayne Jones	Binghamton University, Chemistry Department	Department Chairman	Consultation on alternative solutions	wjones@binghamton.edu
Kenneth Marzolf Jr.	Self-employed	Private Pilot	Pilot's perspective on use of glasses or visor	kenmarzolf@hotmail.com
Kenneth Skorenko	Binghamton University, Chemistry Department	Ph.D. Candidate	Development of selectively laser-resistant spray	kskoren1@binghamton.edu
Thor Solberg III	Self-employed	Private Pilot	Development of project ideas	solberg.thor@gmail.com
Harvey Stenger	Binghamton University	President of Binghamton University and Chemical Engineer	Technical aspects of laser-resistant glass	hstenger@binghamton.edu

Figure 25 - Professional contact information

The team visited BGM on February 11, 2014 to meet with the aviation experts who evaluated the ideas of the project and provided important information from the industry perspective. The team met with Commissioner Carl Beardsley, Charles Howe, and Doug Goodrich who each gave valuable advice and feedback for the team to consider for the project. Charles Howe is an electrical engineer from McFarland Johnson Inc. He works on the maintenance of the lighting systems of all of the runways at BGM. As shown in Figure 26, he began by showing us a basic layout of both runways and discussing the requirements of the

Figure 26 - Charles Howe describes the layout of the BGM runways

lighting systems that are made standard across all airports by the FAA. These runway lights are critical for the pilot to be able to see clearly and navigate safely.

Charles mentioned that MALSR (Medium Intensity Approach Lighting System with Runway Alignment Indicator Lights) are placed beyond the runway at many airports to help aid the pilot in locating the runway environment. He also noted that runway threshold lights are green lights that may conflict with the team's solution. However, as previously discussed in the Risk Assessment, the potential danger caused by not being able to see the threshold lights is very low.

Figure 27 - Commissioner Beardsley discusses ideas with project leader Matthew Stupak

Pictured in Figure 27, Commissioner Carl R. Beardsley Jr., the Commissioner of Aviation of BGM, provided practical advice for the implementation of the team's project. Commissioner Beardsley mentioned that even though BGM has never had a reported laser attack, based on his experiences, any risk, regardless of its frequency, should be addressed. He agreed with the practicality of the use of laser resistant glasses and advised that if it were to be implemented that it be located in a standard place within the cockpit. Commissioner Beardsley also described the use of a pilot's checklist for landing. The use of glasses or a visor could be added to such a checklist as a standard practice.

As a pilot himself, Doug Goodrich of Goodrich Aviation provided useful information about what aspects of the proposal could potentially inconvenience operators. Goodrich noted that many pilots are currently aware of the laser-protective glasses available, however, many choose not to use them because of their clunky, unappealing designs. He suggested that pilots may be more inclined to wear protective glasses if they only needed to be worn for short periods of time. The team implemented this advice by limiting eyewear/visor use to the ten nautical mile range in which laser events tend to occur. Furthermore, Goodrich explained that the risk for laser events would likely be far greater during landing than take-off, as the angle of the plane while ascending makes it difficult for laser light to reach the cockpit.

Figure 28 - Doug Goodrich shows the team around the hangar

Goodrich proceeded to give students a brief tour of his hangar at BGM, shown in Figure 28. Here, the team was able to observe firsthand how easily a green laser would permeate the glass and sun visors covering a cockpit. It was also during this tour that Goodrich pointed out the extensive use of green light-emitting diode (LED) display systems on newer planes. This information influenced the team's ultimate design choice, as visors seemed to be a safer option on newer, commercial planes due to the potential for glasses to interfere with instrument readings.

On March 6, 2014, Binghamton University – State University of New York President Harvey Stenger, Charles Howe, and Commissioner Carl Beardsley came to evaluate the team's proposal based on a presentation given by design team members David Bravo and Jack Fischer, shown in

Figure 29 - David Bravo and Jack Fischer of the design team present the proposal to President Harvey Stenger

Figure 29. President Stenger felt that the proposal's flexibility with the use of both visors and glasses depending on the specific aircraft was a good design choice. Both Charles Howe and Commissioner Beardsley agreed that by avoiding a one-size-fits-all solution, the proposal showed more promise.

Overall the team's trip to BGM yielded a wealth of information that would help shape the final proposal. Feedback from expert advisors in the aviation industry ultimately clarified a number of concerns held by team members as they discussed a solution to the growing string of laser attacks. Specifically, the advice strengthened the idea that visors and glasses of a similar material should be situationally implemented depending on the aircraft in question. Additionally, the red tape surrounding aircraft modifications drove the team toward simpler, more elegant solutions to the problem.

VIII. Conclusion

In their final approach, pilots are vulnerable to laser attacks. Laser illuminations are a serious and growing problem for the whole aviation community, including the FAA. The beams of a laser may startle and even blind pilots during the most critical phases of flight. This may cause vision impairment and even loss of control over an aircraft, which would ultimately lead to a very hazardous scenario. The FAA has recognized the danger posed by these attacks, and has taken steps to try to remedy the situation.

The current solution is to report laser incidents to the FAA, which, ultimately, does not reduce the threat when one takes place. For pilots, the only option is to shield their eyes with their hands or by turning away from the laser. However, neither movement is advisable during takeoff or landing, as it would only cause further problems.

The Binghamton University – State University of New York team has developed an active solution that protects the pilot during an attack. The pilots' eyes are protected by filtered glass that blocks laser light at green frequencies. The solution is implemented in two parts: a laser shield similar to a visor, and individual protective eye-glasses for pilots to use. Commercial aircraft are strongly encouraged to use both. Once an incident takes place, a pilot is to communicate with Air Traffic Control, who in turn warns all other pilots that a laser attack is taking place. Pilots respond to this alert by lowering their laser shields until ATC indicates that the event has passed. With such an approach, the FAA will mitigate the threat of laser attacks and produce a more seamless and secure flight environment for everyone.

Appendix A: List of Complete Contact Info

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Appendix B: Description of Binghamton University

i. History

Figure 30 - Aerial View of Binghamton University Campus [53]

Binghamton University – State University of New York was originally founded in 1946 as Triple Cities College, an off-shoot of Syracuse University created to aid veterans returning from combat in World War II. Its campus lay in Endicott, New York, five miles away from its present location. After four years, the college was renamed Harpur College after Robert Harpur, a colonial teacher and pioneer famous to the area. In 1961 the Harpur College campus was moved to Vestal, where it exists today as shown in Figure 30. In 1965 the college was formally named the State University of New York at Binghamton. Decades later, the school informally adopted the name Binghamton University [52].

ii. Admissions Data

13,013 undergraduate students and 3,085 graduate students currently study at Binghamton University. The average high school grade point average (GPA) of enrolled students ranges from 91 to 97; additionally, the average transfer student GPA is 3.4/4.0. The mid-range SAT scores of Binghamton University students are 620 to 710 in math, 600 to 680 in critical reading, and 580 to 670 in writing. Those who opted to take the ACT boasted mid-range scores from 26 to 31 [54]. The New York Times reports that Binghamton University received 29,104 applications in 2013 and that it had a selective admittance rate of 40.3% [55].

iii. Academics

Binghamton University currently hosts over 130 undergraduate academic offerings and 70 different programs for graduate students [56]. Classroom activities aside, Binghamton University offers a wide variety of research opportunities to both graduate and undergraduate students alike; the 30 available centers for research give students the chance to work alongside pioneers in their respective fields [57].

Within Binghamton University there are six different schools and colleges, each of which hosts its own array of courses. These include the Harpur College of Arts and Sciences, the Thomas J. Watson School of Engineering and Applied Science, the Decker School of Nursing, the College of Community and Public Affairs, the School of Management, and the Graduate School of Education [58]. Binghamton University currently offers a number of Master's degrees, Doctoral Degrees, accelerated degrees, various certifications, and non-matriculated study opportunities [59].

iv. Accolades

Known for its exceptional value as an educational institution, Binghamton University has become one of the most well-recognized public universities in the United States. US News and World Report ranked Binghamton University 97th among the top 100 national universities in its 2014 survey [60]. Based on academics, costs, and financial aid policy, The Princeton Review ranked Binghamton University tenth among the best value public colleges in the United States [61]. Kiplinger's Best Values in Public Colleges List rated Binghamton University the fourth best college choice for out-of-state students and the fifteenth for in-state students [62]. Binghamton University is often referred to as a "Public Ivy," and has proudly been called the “premier public university in the northeast” by the Fiske Guide to Colleges due to its academic rigor and affordable cost [63].

Appendix C: Description of Non-University Partners

i. McFarland Johnson Incorporated

Founded in 1946, McFarland Johnson Incorporated (MJ) is an engineering consulting firm that specializes in infrastructure planning, infrastructure design, and construction management. Based out of Binghamton, New York, McFarland Johnson, Inc. offers a wide range of services across several disciplines of engineering. These involve a variety of infrastructure-based projects including the development of aviation facilities, bridges, highways, and other buildings. In addition to its skill in surveying and sustainability planning, the company has unmatched expertise in civil, site, structural, electrical, hydrological, and environmental engineering. The firm’s interior and employees are pictured in Figure 31.

Figure 31 - Staff of McFarland Johnson’s Company Headquarters

Additionally McFarland Johnson, Inc. has branches in Connecticut, New Hampshire, and various other parts of the Northeast [64]. McFarland Johnson, Inc. has worked on many projects in the Northeast, several of which have won distinguished awards from the engineering community [65].

McFarland Johnson, Inc. has been a member of the U.S. Green Building Council for several years and has made a commitment to sustainability by implementing new technologies and innovative designs in its work. Its staff includes Leadership in Energy & Environmental Design (LEED) Accredited Professionals, as well as individuals with energy management and sustainable development certification [66]. The Binghamton Intermodal Transit Terminal, which was completed in 2010, is one example of a recent project focused around sustainability. Another such example is the Sustainable Master Plan, which is currently being integrated into the Buffalo Niagara International Airport after its approval in June of 2013 [67].

In 2013, McFarland Johnson, Inc. received two awards from the American Council of Engineering that highlight the company's expertise in the aviation and transportation industries. The first was a platinum award for a plan to extend the Elmira Corning Regional Airport's runway. The project was first rejected because of its proximity to the nearby Sing Sing Creek, but due to MJ's creative efforts, the project was approved with overwhelming support [68]. The second was the realignment of Route 17 near Parksville, New York that won a Diamond award for its low impact design, which mitigated damage to the environmentally sensitive Beamoc watershed [69]. McFarland Johnson, Inc. also received first place in the Phil Brito Project of the Year Award for the runway design used at Elmira Corning Regional Airport. Additionally, McFarland Johnson, Inc. earned a second place award for a runway renovation at Greater Binghamton Airport [69].

ii. Greater Binghamton Airport


Figure 32 - Aerial View of the BGM [71]

The Greater Binghamton Airport (BGM) is located on Edwin A Link Field, shown in Figure 32, eight miles away from Binghamton in Johnson City, New York. It services the Triple cities area as well as the surrounding counties of Upstate New York and Northeast Pennsylvania. The three major airlines that operate at BGM are United Airlines, U.S. Airways, and Delta that service non-stop flights to Washington D.C. (Dulles), Philadelphia, and Detroit [70].

The Greater Binghamton Airport covers 1,199 acres of land and includes two 150 foot wide asphalt runways designated 10/28 and 16/34 that are 5,001 feet and 7,304 feet long respectively [71]. Runway 16/34 is the primary runway used for commercial airplanes and its Engineered Material Arresting System was renovated in 2012 to ensure the safety of aircraft landing on the runway by stopping the aircraft in the event of an overshot [72]. According to the National Plan of Integrated Airport Systems, the Greater Binghamton Airport is a publicly owned airport that classifies as a medium-sized, commercial non-hub airport with 109,988 enplanements in 2010 [73]. Its fixed base operator is First Air, and it collaborates with several other aviation companies including Goodrich Aviation, AeroTechniques, and GamaAviation. BGM also has a newly renovated 21,000 square foot hangar for aircraft available for leasing to private individuals or businesses [74].

Appendix E: Evaluation of the Educational Experiences Provided by the Project

i. Student Evaluation

1. Did the FAA Design Competition provide a meaningful learning experience for you? Why or why not?

The FAA Design Competition is the centerpiece of a fantastic learning opportunity. Before working on the design for this competition, many of the university students had never participated in a large-scale project before. Managing a project in a nine person group gave students an understanding of general project organization and structure. Students were broken into sub-teams and learned how to operate with a partner on small tasks while contributing to a grander goal in a big group.

Additionally, the FAA Design Competition gave students the opportunity to work closely with professionals in the highly technical field of aviation. Students learned firsthand how to professionally contact and converse with experts. These connections were maintained and used as reference points throughout the project. Technology was used extensively in the project. Team members became well versed in e-mail communication, cloud storage and presentation software. Internet research was used as well. Overall, the FAA Design Competition was the catalyst for this unique learning experience.

2. What challenges did you and/or your team encounter in undertaking the Competition? How did you overcome them?

The greatest challenge the team faced was the diverse background the team members had. The participants came from widely varied fields of study. Students majoring in Accounting, Actuarial Science, Biology, Computer Science, and English had to work together on this project.

To smooth over any incompatibilities, the team as a whole broke into smaller subgroups. These groups specialized in familiar fields. For example, the Actuarial Science majors handled Risk Assessment, and the Computer Science majors worked in the Design Team. The specialization allowed all the students to operate well in comfortable fields.

Another large challenge was unfamiliarity. To remedy the lack of knowledge, the team took a trip to Greater Binghamton Airport to meet with airport professionals. The team had numerous meetings and telephone conversations with aviation professionals. Also, team members extensively researched essential FAA documents and data. These sources provided the necessary information for the team.

3. Describe the process your team used for developing your hypothesis.

The team's hypothesis was developed in three steps. First, project leader Matthew Stupak introduced the threat of laser attacks to the team. Matthew demonstrated the growing danger lasers pose to the aviation industry. The team selected laser strikes as the topic it wanted to address.

Next, the team performed a literature review to obtain a greater understanding of the issue. The team familiarized itself with the overall danger lasers pose, the increase in frequency in attacks and the current protocols the FAA has in place to mitigate these attacks. The team also researched potential ways to block lasers such as glasses used in laser manufacturing industries and visors used by military personnel during critical operations in hazardous/dangerous areas.

Finally, the team met with representatives from Greater Binghamton Airport and McFarland Johnson to seek their opinions. The representatives allowed the team to examine several cockpits of aircraft. Using the advice of the professionals and the results of the cockpit examinations, the team developed the final hypothesis. A combination of a laser shield visor and protective eyeglasses was agreed upon as the solution.

4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?

Participation from industry partners contributed greatly to the proposal. The team was able to visit the Greater Binghamton Airport to consult Commissioner Carl Beardsley, Charles Howe of McFarland Johnson, Inc. and Doug Goodrich CEO of Goodrich Aviation.

Commissioner Beardsley critiqued the team's design from the perspective of both an airport operator and a pilot. Commissioner Beardsley also directed the team to useful FAA Advisory Circulars and guidelines. Mr. Goodrich showed the team the interiors of the aircraft owned by his business and Mr. Howe gave us critical information regarding runway lighting and safety. The intimate look at the cockpits was crucial for the implementation of the design. Mr. Goodrich, Commissioner Beardsley and Mr. Howe agreed that a non-intrusive, simple solution was the best design. Their input was critical in choosing a flip visor and protective glasses as the proposal.

Furthermore, the team consulted many other industry experts in order to get their professional opinions. The list of all industry contacts used throughout the project is shown in Figure 25. As a team, we had to collaborate and communicate with these experts who had an inside perspective of issues in the aviation industry.

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

This project provided an excellent opportunity to develop skills that are highly coveted in today's workforce. Comprehensive group work, forthright leadership, and problem solving skills are fantastic traits to hone in a university environment. Students actively worked to solve a real world problem. They were challenged to produce standpoints and defend them in writing and speech. An emphasis on organization and communication was present as well. Above all, developing problem solving skills was the most important experience throughout this project. As a team we learned how to work together, communicate effectively, encounter problems beyond our experiences, break it down to its simplest form, and create an effective solution. The use of presentation and data manipulation software, cloud storage and electronic communication was also universal among all members. The knowledge gained from its usage is sure to be helpful in the workforce or in further study.

ii. Faculty Evaluation

l. Describe the value of the educational experience for your student(s) participating in this Competition submission.

As a lifetime student myself, I am a firm believer in continuing the educational process and doing so in a manner that has a lasting effect. While lecturing and laboratory time have great value they are limited in their ability to allow students a blank slate to work from. The FAA Design Competition provides the opportunity for students to take an idea, their idea, all the way from the brainstorming stage to a well-researched concept that has real potential for implementation. Creating their own solutions that do not currently exist for challenges facing an industry such as aviation allows the students to take true ownership in the educational experience.

Over the course of the design competition, a team of diverse students had to not only develop a sound proposal but also gain trust in each other by working in teams. Individually and collectively they had to deliver on milestones each week to ensure that the proposal stayed on track for meeting the submission deadline. This is a life skill that cannot be easily taught in class and the FAA Design Competition provides this critical educational opportunity.

2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?

The students involved in the design competition are not accustomed to working in a large group (20 students +/-). This opportunity required a high level of effective communication, management of schedule and assets in the form of smaller teams working on individual project components. Although this was new ground for most of the students, it pushed them to improve their communication and time management skills. This is a key element of the learning experience and one that will help the students as they complete their education and move into a career. Overall the experience was appropriate and effective.

3. What challenges did the students face and overcome?

The students had several challenges to overcome during the development of their proposal for the competition. Creating a design proposal from scratch is something that they have never undertaken before. They are similarly not familiar with working in a large team, which presented an additional challenge to the proposal development. Lastly, the competition deadline requires that they work quickly, with minimal rework and that time within the project team and external industry advisors is effective and efficient.

Regarding the development of the proposal from scratch; the team was able to overcome this challenge through the tireless efforts of the project leader. The project leader set the tempo and checked in frequently with the team to organize assignments and make sure that the groups involved in the proposal were working cohesively.

The challenge of working in such a large team was mitigated by using smaller groups of students to head up individual elements of the proposal. The course that was taught, which used the FAA Design Competition as the basis of semester's work, was Project Management. The students treated the competition as a project and the management of the proposal was handled exactly as a project manager would handle a large project.

The competition deadline, while challenging, was achieved through disciplined delegation of duties through the entire project team. The entire class was well aware that if any of the students or the teams did not perform at the highest level that the entire team would suffer. This created a camaraderie amongst the team that was evident during weekly check-ins where team members provided me assessments or 'grades' of how the other team members were performing within the group.

4. Would you use this Competition as an educational vehicle in the future? Why or why not?

I would highly recommend this competition to future students and faculty. As previously mentioned; this particular competition gives students a very different experience than they gain from typical courses and classroom activities. The significant collaborative effort that is required to develop a winning proposal is something that cannot be easily taught. This competition provides for an educational experience on communication, time management, team building and original writing that will serve the students well as they enter the workforce. I am confident that you will see Binghamton University participating in the competition again.

5. Are there changes to the Competition that you would suggest for future years?

New topics and categories have been added this past year to the competition. This is important to keep the competition interesting and relevant. The continued addition of new areas of focus would be my primary recommendation for future years. The FAA may also want to consider a research and development pipeline tied to winning proposals. Not all of the ideas are easily adopted; however certain proposals should be advanced to at least the prototype level and possibly beyond. Ultimately the competition serves as an important introduction to innovation in the aviation industry but could be more with additional federal funding and visibility to potential private investors. Overall, the competition is extremely well run and represents the type of educational opportunity that is critically needed in academia.

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