Federal Aviation Administration

DOT/FAA/AM-13/8
Office of Aerospace Medicine
Washington, DC 20591

Laser Illumination of Helicopters: A Comparative Analysis With Fixed-Wing Aircraft for the Period 1980 – 2011

Ron W. Montgomery
Kathryn J. Wood

Civil Aerospace Medical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

April 2013

Final Report

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AM-13/8		

4. Title and Subtitle	5. Report Date
Laser Illumination of Helicopters: A Comparative Analysis With Fixed-Wing Aircraft for the Period 1980 – 2011	April 2013
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Montgomery RW, Wood KJ	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
FAA Civil Aerospace Medical Institute P.O. Box 25082 Oklahoma City, OK 73125	11. Contract or Grant No.
12. Sponsoring Agency name and Address	13. Type of Report and Period Covered
Office of Aerospace Medicine Federal Aviation Administration 800 Independence Ave., S.W. Washington, DC 20591	14. Sponsoring Agency Code

15. Supplemental Notes

16. Abstract

INTRODUCTION. Laser illuminations of aircraft have resulted in pilots reporting distraction, disruption, disorientation, adverse visual effects, and operational problems that put at risk the safety of the aircraft and those onboard. FAA Order 7400.2 was revised in 1995 to establish lower laser exposure limits that protected flight crewmembers in specific zones of airspace around airports. However, helicopters (including police, air ambulance, military, and news media aircraft) that routinely operate at low altitudes outside these zones continue to be exposed to hazardous levels of laser radiation. This study examines the frequency of these events and adverse effects of laser illuminations involving helicopters compared with fixed-wing aircraft for a 32-year study period (from January 1, 1980 to December 31, 2011). METHODS. Reports of helicopters and fixed-wing aircraft illuminated by high-intensity light have been collected from various sources and entered into a database maintained by the Vision Research Team at the FAA Civil Aerospace Medical Institute. The frequency of laser illumination events involving aircraft in the United States were stratified by altitude into 1,000-foot increments, categorized, and analyzed. Analysis included identifying adverse effects experienced by helicopter flight crewmembers, compared to those experienced by crewmembers of fixed-wing aircraft. RESULTS. The majority of helicopter laser exposures (70% or 751/1,072) were within the altitude limit established for the Laser Free Zone (LFZ $\leq$ 2,000 feet) versus only 18% (1,980/11,111) for fixed-wing aircraft. More than 86% (328/379) of all adverse effects reported by helicopter pilots were in this altitude range, compared to 29% (294/1,027) of all fixed-wing effects reported. CONCLUSION: Special protective measures may be needed for helicopters and other low-flying aircraft outside of designated airport hazard zones due to the higher percentage of adverse effects associated with these events and the increased risk inherent in low-altitude flight operations.

17. Key Words	18. Distribution Statement
Vision, Visual Impairment, Lasers, Aviation, Helicopter, Fixed-wing Aircraft, Adverse Effects, Altitude	Document is available to the public through the Internet: www.faa.gov/go/oamtechreports

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	9	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Laser Illumination of Helicopters: A Comparative Analysis With Fixed-Wing Aircraft for the Period 1980 – 2011

INTRODUCTION

Reports of laser beams illuminating aircraft and flight crewmembers have been documented since the 1980s. Initially, these reports were considered inconsequential due to their rarity and since the irradiance (or exposure level) was below that which could cause biological damage, i.e., a maximum permissible exposure, or MPE (1). However, as the frequency of these incidents increased, so did reports of operational problems caused by distraction, disorientation, temporary visual impairment (i.e., glare, flashblindness, and afterimages) and, in rare instances, injury (2,3). These events mostly occur at night, when the airman's' eyes are adapted to mesopic conditions (dim lighting). In such circumstances, exposure to even low levels of laser radiation can have serious adverse effects on a pilot's vision (see Figure 1). The operational problems that can result from these exposures during critical phases of flight (e.g., landings and takeoffs) can place the safety of the aircraft and the individuals onboard at great risk. The hazards associated with laser illuminations increase as altitude decreases, independent of the level of exposure (4).

A sharp rise in the number of laser incidents reported in the mid-1990s resulted in a revision of FAA Order 7400.2, entitled "Procedures for Handling Airspace Matters, Part 6. Miscellaneous Procedures, Chapter 29. Outdoor Laser Operations," to establish lower laser exposure limits to protect flight crewmembers in specific zones of airspace around airports (5). Prior to this change, flight crewmembers were only protected from exposure levels that could cause ocular tissue damage or MPE (1). The revised FAA Order reduces the permissible laser exposure levels in airspace around airports called flight hazard zones (see Figure 2). These zones include the Normal Flight Zone (NFZ), Sensitive Flight Zone (SFZ), Critical Flight Zone (CFZ), and Laser Free Flight Zone (LFZ). Laser exposure levels were established for each flight hazard zone to not exceed the following limits:

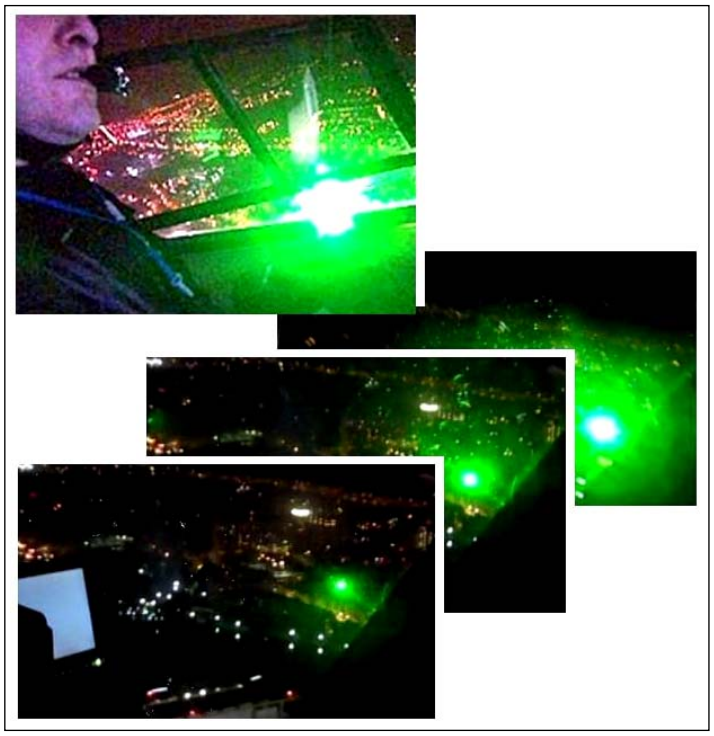

Figure 1: Example of laser illumination of helicopter at night

- NFZ = 2.54 milliwatt per square centimeter (μW/cm2)
- SFZ = 100 microwatt per square centimeter (μW/cm2)
- CFZ = 5 μW/cm2
- LFZ = 50 nanowatt per square centimeter (μW/cm2)

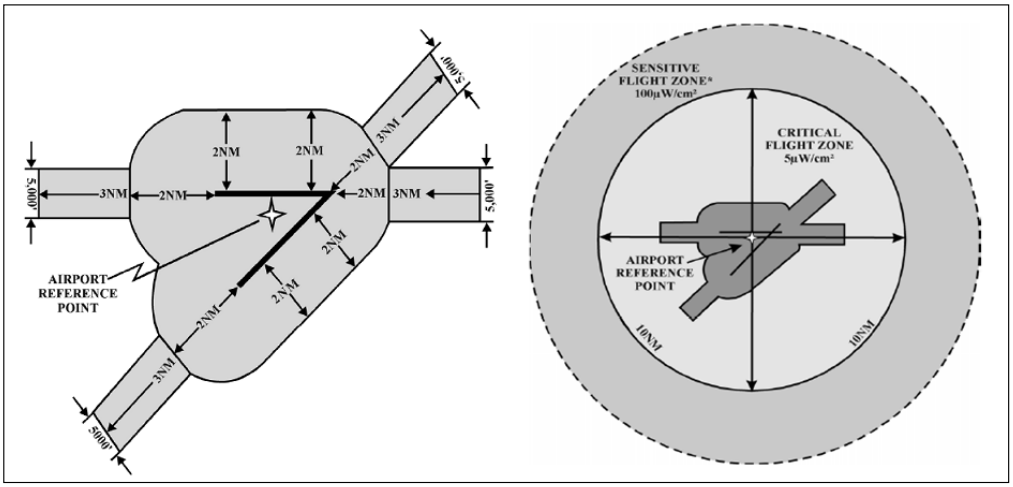

Figure 2: The LFZ (left) extends up to 2,000 feet above ground level (AGL) and 2 nautical miles (NM) in all directions from the runway centerline. It includes an additional 3-NM extension along the runway centerline. The CFZ (right) includes all airspace surrounding the LFZ within a 10-NM radius of the airport reference point, up to 10,000 feet AGL. The SFZ includes airspace outside the Laser-Free and Critical Flight Zones that authorities identify as requiring protection from the potential visual effects of laser beams. The NFZ (not depicted) include all airspace outside all other designated flight hazard zones.

During the fall of 2004, another spike in the number of laser illumination incidents resulted in the issuance of an FAA Advisory Circular (AC) entitled "Reporting of Laser Illumination of Aircraft" (AC 70-2) on January 12, 2005 (6,7). The AC includes instructions for flight crewmembers and air traffic personnel on how to report laser events and a "Laser Beam Exposure Questionnaire" to be completed by the exposed individual(s) or aviation personnel tasked with reporting the event. Examination and analysis of these reports is performed to identify patterns or similarities of such laser incidents that allow regulatory agencies to develop guidelines or policies for the prevention and mitigation of this threat to aviation safety. In addition, AC 70-2 was intended to improve coordination between local aviation authorities and law enforcement agencies to aid in the apprehension and prosecution of perpetrators.

Research has shown that the flight crews of low-flying aircraft are particularly vulnerable to the adverse effects of laser exposure (4). One study indicated that the rate at which cockpits were being illuminated (at or below 2,000 feet) had more than doubled during a 5-year period (2004 - 2008) (8). An estimated 10% of these events involved helicopters (including police, air ambulance, military, and news media aircraft) that routinely operate at low altitudes outside protected zones and continue to be exposed to hazardous levels of laser radiation. These aircraft are at greater risk from the adverse effects of laser exposure due to closer proximity to the laser source and to obstacles on the ground. This study examined the event frequency and adverse effects of laser illuminations involving helicopters, compared to fixed-wing aircraft, for a 32-year study period.

METHODS

A database containing reports of helicopters and fixed-wing aircraft illuminated by high-intensity light has been created and maintained by the Vision Research Team at the FAA Civil Aerospace Medical Institute. Event reports are received from multiple sources, including Washington Operations Control Center, FAA regional offices, Transportation Security Administration, Department of Homeland Security and Federal Bureau of Investigation Information Bulletins, the FAA's Office of Accident Investigation, newspaper and Internet articles, and interviews with illuminated personnel.

The frequency of laser illumination events involving aircraft in the United States from January 1, 1980 to December 31, 2011 were stratified by altitude into 1,000-foot increments and analyzed. Events were categorized by zones of airspace "equivalent in altitude" to established flight hazard zones around airports. Note: An incident's actual proximity to the nearest airport was often not included in the information provided in an event report. For the purpose of this study, incidents that occurred within the range of altitudes defined by a particular flight hazard zone were analyzed and referred to as having occurred within that zone. Analysis included comparison of the frequency of laser events and the adverse effects experienced by rotary-wing (helicopter) flight crewmembers with those experienced by crewmembers of fixed-wing aircraft.

RESULTS

A total of 12,248 aircraft laser illumination events (11,014 fixed-wing and 1,234 rotary-wing aircraft) were reported in the United States during the study period. Altitude information was provided in 10,901 (89.0%) of these event reports.

Of the fixed-wing aircraft illumination events, altitude data were provided in 9,829 (90.2%) reports, and the cockpit was illuminated in 7,389 (75.2%) of these events. Altitude data were used to categorize fixed-wing (aircraft and cockpit) illuminations by flight hazard zone (see Figure 3). The majority

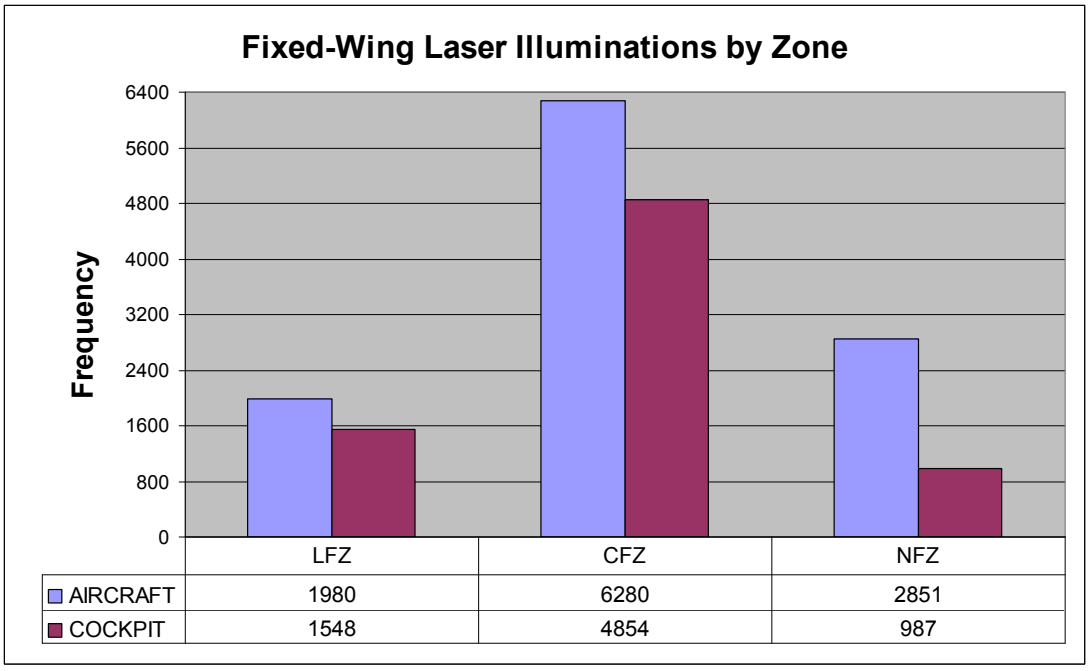

Figure 3: The frequency of fixed-wing aircraft and cockpit illuminations by fight hazard zone

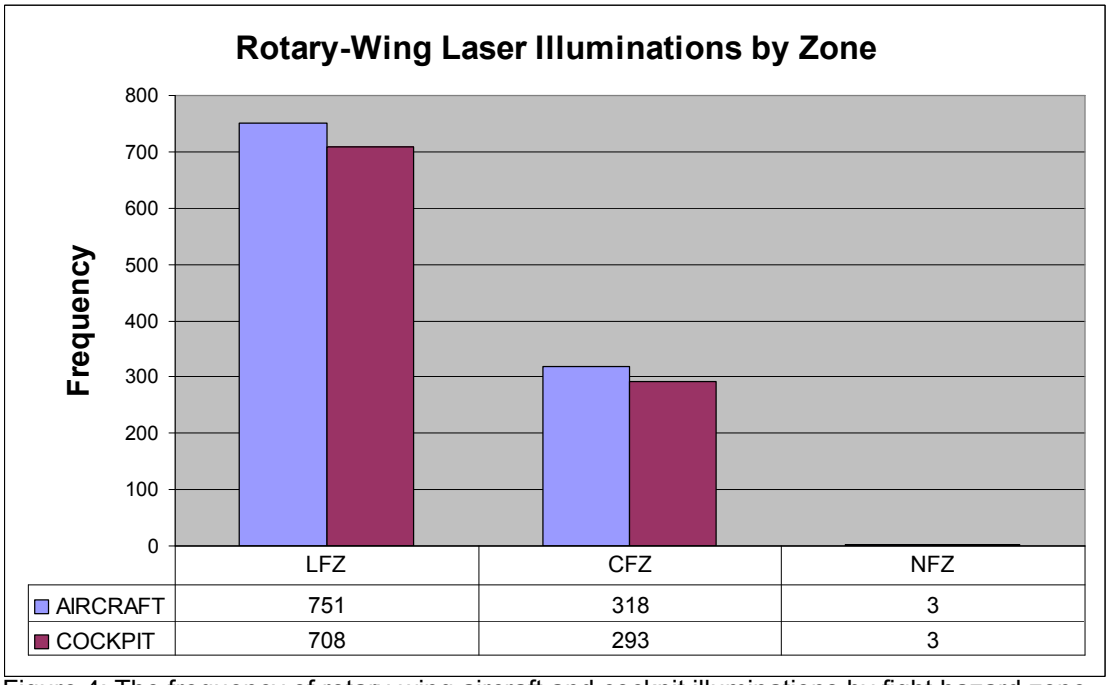

Figure 4: The frequency of rotary-wing aircraft and cockpit illuminations by fight hazard zone

Table 1. Summary of Adverse Effects Experienced by Fixed-wing Flight Crewmembers

Zone: Altitude (ft)	Annoy/ Distract	Visual Effects			Operational Problem	Pain/ Injury	Total Effects	Total Events
		Glare	After-image	Flash-blindness				
LFZ: > 0 - 2,000	83	67	38	56	26	24	294	190
CFZ: > 2,000 - 10,000	209	139	69	89	67	48	621	422
NFZ: > 10,000	34	26	10	16	11	15	112	79
Total	326	232	117	161	104	87	1,027	691

of fixed-wing cockpit illuminations (4,854 or 65.7%) occurred in the Critical Flight Zone.

For rotary-wing aircraft (helicopters), 1,234 (10%) laser illumination events were reported during the study period. Altitude information was provided in 1,072 (87%) of these reports, including 1,004 (97%) incidents in which the cockpit was illuminated. When altitude data were used to categorize rotary-wing aircraft illuminations by flight hazard zone (see Figure 4), the majority of laser exposures (751 or 70%) were found to occur within the altitude limit set by the Laser Free Zone (LFZ ≤ 2,000 feet) versus only 1,980 (18%) reported for fixed-wing aircraft illuminated within this same hazard zone.

The Chi-square test of independence found a statistically significant association (χ^2 = 1,128, d.f. = 2, p ≈ 0) between the type of aircraft (fixed-wing or rotary-wing) and the flight hazard zones in which the illuminations occurred. For example, the odds of a rotary-wing aircraft being exposed to laser radiation at or below 2,000 feet AGL were 2.34:1, while the odds of a fixed-wing aircraft being illuminated in the same zone were 0.22:1.

Of the 7,389 cockpit illumination reports involving fixed-wing aircraft that included altitude data, 691 (9.4%) reported one or more adverse effects, resulting in a total of 1,027 complaints of adverse effects (see Table 1). Of these, 294 (29%) events were reported in the Laser Free Zone, 621 (67%) were in the Critical Flight Zone, and 112 (11%) in the Normal Flight Zone.

Altitude data were provided in 1,004 cockpit illuminations of helicopters. Of these, 213 (21%) reported one or more adverse effects for a total of 379 complaints of adverse effects (see Table 2). The majority (328 or 86%) of all adverse effects reported by helicopter pilots were in the Laser Free Zone, only 51 (13%) in the Critical Flight Zone, and none in the Normal Flight Zone.

Fixed-wing crewmembers reported more adverse effects than did helicopter crewmembers (1,027 vs. 379, respectively); however, helicopter crewmembers reported adverse effects at a higher rate than did fixed-wing flight crewmembers (1.77 versus 1.49 per event, respectively).

Table 2. Summary of Adverse Effects Experienced by Helicopter Flight Crewmembers								
Zone: Altitude (ft)	Annoy/ Distract	Visual Effects			Operational Problem	Pain/ Injury	Total Effects	Total Events
		Glare	After-image	Flash-blindness				
LFZ: > 0 - 2,000	63	60	45	57	69	34	328	188
CFZ: > 2,000 - 10,000	16	10	2	6	12	5	51	25
NFZ: > 10,000	0	0	0	0	0	0	0	0
Total	79	70	47	63	81	39	379	213

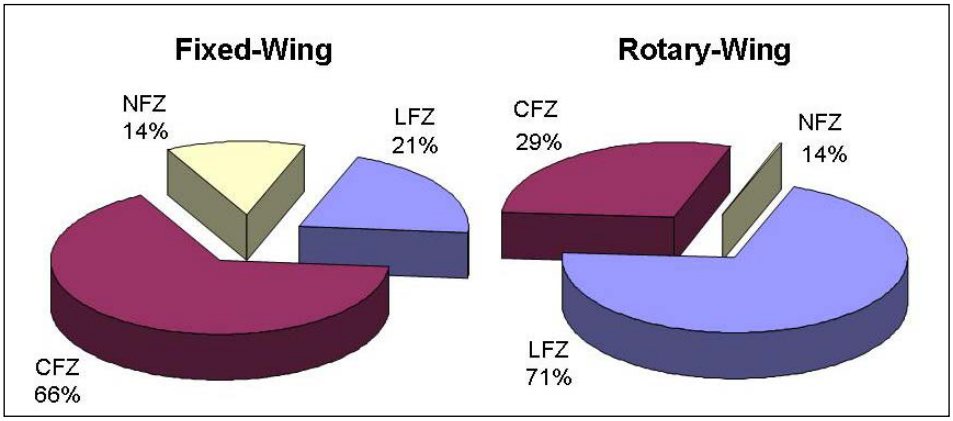

Figure 5: Percentage of fixed-wing and rotary-wing cockpit illuminations by flight hazard zone

Table 3. Percentage of Adverse Effects by Type of Flight						
	MED	COM	LAW	MIL	GA	OTHER
Fixed-wing	**1.3%**	**79.1%**	**1.1%**	**2.9%**	**11.7%**	**3.9%**
Rotary-wing	**18.3%**	**5.7%**	**51.5%**	**10.5%**	**3.8%**	**10.2%**
Abbreviations: MED (Medical Evacuation), COM (Commercial), LAW (Law Enforcement), MIL (Military), GA (General Aviation), OTHER (Freight, Corporate, Unknown)						

DISCUSSION

During the study period, a total of 12,248 laser illumination events were reported. Of that total, altitude data were available in 10,901 (89%) reports, and cockpit illuminations were reported in 8,393 (77%) of these events. Fixed-wing aircraft accounted for 7,389 (88%) of these events, while rotary-wing aircraft (helicopters) were involved in 1,004 (12%) events, a ratio of more than 7:1.

The percentage of fixed-wing and rotary-wing cockpit illuminations by the flight hazard zones in which they occurred are summarized in Figure 5. Helicopters were illuminated less frequently but at a higher percentage compared to fix-wing aircraft (71% vs. 21%, respectively) at altitudes equivalent to those defined by the Laser Free Zone (≤ 2,000 feet). Helicopters routinely operate at lower attitudes and slower speeds than fixed-wing aircraft, making them easy targets for laser beam illuminations. In addition, helicopters often fly from heliports that are not located near the protected zones of airspace surrounding airports.

On the other hand, the percentage of fixed-wing aircraft illuminations was highest (66%) within the altitude limits of the Critical Flight Zone (> 2,000 to ≤ 10,000 feet). At higher altitudes, the perpetrator can target aircraft from the relative anonymity of a remote location. To target an aircraft that is in the Laser Free Zone of an airport requires the individual to be close to the airport perimeter, where there may be more public scrutiny, airport security personnel, or local police patrols. In addition, as a fixed-wing aircraft approaches the runway, the nose is elevated making a cockpit illumination from ground level more difficult.

Reports of adverse effects from laser illuminations by the type of flight operation are summarized in Table 3. Flight crewmembers operating commercial aircraft reported the highest percentage (79.1%) of adverse effects for fixed-wing aircraft, while law enforcement crewmembers reported the largest

percentage (51.5%) of adverse effects among the rotary-wing aircraft. The former is likely due to the disproportionately larger number of flights and flight hours logged by commercial aircraft, which would increase the probability of being targeted. One explanation for the high percentage of police helicopter illuminations is that they are often sent to investigate after other aircraft have been illuminated, placing them in airspace where laser exposures have already occurred and are more likely to happen again. Ironically, the perpetrators have often illuminated police helicopters, thereby revealing their location and assisting in their own arrest.

Besides being easier targets due to their low and slow flight profiles, helicopter flight crewmembers may also be more susceptible to visual impairment from laser beam exposures due to the large bubble canopies characteristic of these aircraft. These canopies can allow more light to enter at various angles to scatter and reflect throughout the cockpit, thereby increasing the chances for adverse visual and/or operational effects. In addition, pilots have described a sudden luminescence enveloping the entire canopy as the laser light refracts (bends) within the plastic (acrylic) material. A study conducted in the Netherlands investigated the visual and biological effects experienced by a helicopter pilot exposed to several broadband high-intensity light sources and a common 3.5mW green (532 nm) laser pointer (9). The study concluded that there is no need to restrict high-intensity light sources pointing in navigable airspace anywhere outside the Laser Free Zone. However, the study indicated that use of high-intensity light sources inside the Laser Free Zone should be avoided since they can cause distraction. Intentionally tracking aircraft with a high intensity light, and especially with lasers, can seriously impair pilot vision. It was noted that none of the broadband high-intensity light sources used in the study produced glare effects comparable to that of the green laser pointer.

CONCLUSIONS

The comparative analysis performed in this study indicates that rotary-wing aircraft are more vulnerable at low altitude to laser illumination than fixed-wing aircraft. This study found that 70% of helicopter illuminations occurred at altitudes equivalent to those of the Laser Free Zone (≤ 2,000 feet), while only 18% of fixed-wing aircraft were targeted within the same attitude limits. Although the cockpits of fixed-wing aircraft were illuminated more frequently than helicopters (7.4:1 ratio), helicopter crewmembers reported higher rates of adverse effects than fixed-wing flight crewmembers (1.77 versus 1.49 per event, respectively) at or below 2,000 feet. Based on the findings of this study and the nature of rotary-wing operations, special protective and preventative measures may be needed for helicopters and other low-flying aircraft outside of designated airport flight hazard zones due to the higher percentage of illuminations reported and the increased rate of adverse effects associated with these events. These results may also justify the expense of equipping rotary-wing aircraft (particularly law enforcement aircraft) with laser detection and tracking devices to improve the possibility of apprehending perpetrators of these offences. Continued monitoring of these events is recommended to evaluate the use of new laser technologies outdoors that could warrant a change in regulatory policy to better protect pilots against the detrimental effects of laser exposure.

REFERENCES

1. American National Standards Institute (ANSI) Z136.6 -2005, American National Standard for Safe Use of Lasers Outdoors. Laser Institute of America, Orlando, FL. At URL: http://webstore.ansi.org/RecordDetail.aspx?sku=ANSI+Z136.1+and+Z136.6+Combination+Set&source=package_landing_page (Accessed December 2012).

2. NASA ASRS Report 322991. December 1995. At URL: http://www.37000feet.com/report/322991/Laser-beams-hitting-aircraft-at-night-Flight-crew-eye-damage (Accessed December 2012).

3. NASA/ASRS. Report Number 354327.November 1996. At URL: http://www.37000feet.com/report/354327/While-on-a-night-visual-approach-to-runway-24R-at-lax-the (Accessed December 2012).

4. Nakagawara VB, Montgomery RW, Dillard AE, McLin LN, Connor CW. The Effects of Laser illumination on operational and visual performance of pilots during final approach. Washington, DC: Federal Aviation Administration, Office of Aerospace Medicine: Report No. DOT/FAA/AM-04/09. June 2004. At URL: http://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2000s/media/0409.pdf (Accessed December 2012).

5. FAA Order 7400.2, Procedures for Handling Airspace Matters, Part 6. Miscellaneous Procedures, Chapter 29. Outdoor Laser Operations. At URL: http://www.faa.gov/air_traffic/publications/atpubs/AIR/air2901.html#air2901.html.1 (Accessed December 2012).

6. Nakagawara VB, Wood KJ, Montgomery RW. A review of recent laser illumination events in the aviation environment. Washington, DC: Federal Aviation Administration, Office of Aerospace Medicine: Report No. DOT/FAA/AM-06/23. Oct 2006. At URL: http://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2000s/media/200623.pdf (Accessed: December 2012).

7. Reporting of laser illumination of aircraft. FAA-A/C No. 70-2. January 11, 2005. At URL: http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/list/AC%2070-2/$FILE/AC%2070-2.pdf (Accessed: December 2012).

8. Nakagawara VB, Montgomery RW, Wood KJ. The Illumination of aircraft at altitude by laser beams: a 5-year study period (2004-2008). Washington, DC: Federal Aviation Administration, Office of Aerospace Medicine. Report No. DOT/FAA/AM-10/21. Dec 2010. At URL: http://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2010s/media/201021.pdf (Accessed: December 2012).

9. Toet A, van der Leden N, Alferdinck JWAM. The outdoor use of laser and other high intensity light sources in relation to air traffic safety. Soesterberg, The Netherlands, TTNO Report: TNO-DV 2009 C264. Jun 2009. At URL: http://www.laserpointersafety.com/LPSFiles/files/TNO-DV%20 2009%20C264.pdf (Accessed: December 2012).