# Evaluation of New Obstruction Lighting Techniques to Reduce Avian Fatalities

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16. Abstract


Wildlife biologists have conducted extensive research to better understand how migratory birds are negatively affected by obstruction lights, which are used at night to warn pilots that they are approaching an obstruction hazard. The research concluded that migratory birds appear to be attracted to the steady-burning (i.e., nonflashing) obstruction lights on communication towers and, as a result, thousands of birds are killed annually through collisions with these obstructions. Wildlife organizations, the telecommunication industry, and the Federal Communication Commission collectively approached the Federal Aviation Administration (FAA) and requested that the FAA consider redefining their standards for obstruction lighting to either omit or flash the normally steady-burning red lights to reduce their impact on the mortality rates of migratory birds.

In the research reported here, the FAA Airport Technology Research and Development Team evaluated the proposal to omit or flash the normally steady-burning red lights. In addition, researchers evaluated the potential benefit of using light-emitting diode obstruction lights instead of conventional incandescent obstruction lights as a way to mitigate their impact on birds, due to their unique color and flash pattern. A series of flight evaluations was conducted to compare the obstruction lighting on several communication towers in the northern Michigan area. A tower that was equipped with a nonstandard lighting configuration in which the steady-burning red lights were programmed to flash in unison with the red flashing lights was also included in the flight evaluation.

The results showed that flashing the steady-burning lights was acceptable for small towers (151 to 350 feet in height) and that they could be omitted on taller towers (over 351 feet) so long as the remaining brighter, flashing lights were operational. The optimal flash rate for the brighter lights to flash simultaneously was determined to be between 27 and 33 flashes per minute (fpm). Flashing at slower speeds (under 27 fpm) did not provide the necessary conspicuity for pilots to clearly acquire the obstruction at night without the steady-burning lights, and flashing at faster speeds (over 33 fpm), the lights were not off long enough to be less of an attractant to migratory birds.

Based on the results of this research, the FAA proposes to make specific changes to the obstruction lighting standards, including a proposal to omit or flash steady-burning red lights from several obstruction lighting configurations.


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|---|---|
| AC | Advisory Circular |
| AGL | Above ground level |
| FAA | Federal Aviation Administration |
| FEMA | Federal Emergency Management Agency |
| FCC | Federal Communication Commission |
| fpm | Flashes per minute |
| FWS | U.S. Fish and Wildlife Service |
| LED | Light-emitting diode |
| OE | Obstruction Evaluation |

# EXECUTIVE SUMMARY

Over the last several years, wildlife biologists have conducted extensive research studies to better understand the negative effects nighttime obstruction lighting on communication towers can have on migratory birds. The results of these studies showed that migratory birds appeared to be more attracted to steady-burning obstruction lights (i.e., nonflashing) than to lights that flashed several times a minute. Based on these studies, wildlife organizations, the telecommunication industry, and the Federal Communication Commission approached the Federal Aviation Administration (FAA) to share the results of their research and requested that the FAA consider redefining the standards for obstruction lighting to omit or flash the normally steady-burning lights, thereby reducing the mortality rates of migratory birds.

The Airport Safety Technology Research and Development Team at the FAA William J. Hughes Technical Center in Atlantic City, New Jersey, conducted a multiphase evaluation to investigate the industry's request. The evaluation addressed two separate elements: (1) the concept of either omitting or flashing the normally steady-burning red lights and (2) the benefits of using new light-emitting diode obstruction lights rather than conventional incandescent obstruction lights. This report details the research activity that was conducted as part of this evaluation, addressing the steady-burning versus flashing light issue and identifying any benefits of new technology lighting.

A series of flight evaluations of several communication towers in the northern Michigan area were conducted, including one in which a tower was equipped with a nonstandard lighting configuration with steady-burning red lights (referred to as L-810) programmed to flash in unison with the red flashing lights. Researchers determined that the flashing of the normally steady-burning red light (the FAA type L-810 fixture) was considered acceptable, and further determined that on tall communication towers, the steady-burning lights could be extinguished altogether so long as the remaining lights flashed simultaneously between 27 and 33 flashes per minute. Flashing at faster speeds did not appear to offer any value because the light fixtures were not off long enough for the light fixture to be completely dark before the next flash cycle started and the light turned back on. This increased the likeliness that birds would be attracted to the tower.

This report summarizes the evaluation effort and provides information on specific changes that will be required to redefine FAA standards to omit steady-burning lights from several lighting configurations and, thus, reduce the mortality of migratory birds.

# INTRODUCTION

## PURPOSE.

Over the last several years, wildlife biologists have conducted extensive research to better understand the negative effects that nighttime obstruction lighting on tall communication towers can have on migratory birds. The results of the research concluded that migratory birds, when traveling at night, are more attracted to steady-burning (i.e., nonflashing) obstruction lights than to lights that flash several times a minute. Wildlife organizations, the telecommunication industry, and the Federal Communication Commission (FCC) collectively approached the Federal Aviation Administration (FAA) to share these results and requested that the FAA consider redefining the standards for obstruction lighting to omit steady-burning lights, and thereby reducing the mortality rates of migratory birds.

The initial request for assistance from industry was received by the FAA Obstruction Evaluation (OE) Group of the System Operations and Aeronautical Information Management Air Traffic Organization. The OE Group is responsible for evaluating the effect structures may have on the National Airspace System, and for developing, maintaining, and updating FAA Advisory Circular (AC) 70/7460-1 [1]. The OE Group requested the assistance of the FAA Office of Airport Safety and Standards, AAS-100, FAA Headquarters, in Washington, DC, which has the ability to conduct the necessary field research required to evaluate the industry's request. This office is also responsible for developing and maintaining AC 150/5345-43, which provides technical specifications for the lighting equipment used to illuminate obstructions.

AAS-100 presented a request for research to the Airport Safety Research Section at the FAA William J. Hughes Technical Center, Atlantic City International Airport, New Jersey. This request focused on two elements: (1) evaluating the concept of either omitting or replacing the steady-burning red lights with flashing lights and (2) evaluating the benefits of using light-emitting diode (LED) obstruction lights rather than conventional incandescent obstruction lights. This report details a multiphase evaluation that addressed the steady-burning versus flashing light issue and identified any benefits of new technology lighting.

## OBJECTIVES.

The objectives of this research were to conduct a multiphase evaluation to determine if the standards for obstruction lighting and marking could be updated to reduce the negative impact on migratory birds. Specifically, this research effort included the following:

1. Determine if the nonstandard lighting configuration on the WPBN television station tower in Harrietta, Michigan, provides sufficient conspicuity for pilots.

2. Determine the effects of flashing the normally steady-burning red obstruction lights simultaneously with the other flashing red lights.

3. Determine the effects of omitting the normally steady-burning red obstruction lights from FAA lighting configurations.

4. Identify required changes to FAA obstruction lighting standards to incorporate lighting configurations that would reduce migratory bird mortality.

5. Determine if new lighting technologies, such as LED, offer any benefit over conventional incandescent lights.

## BACKGROUND

Since the 1960s, numerous researchers, biologists, and conservation groups have conducted ongoing studies to document avian collisions with man-made obstructions, such as buildings, communication towers, power lines, and wind turbines. The United States Fish and Wildlife Service (FWS), in several publications, has estimated that 4 to 5 million birds are killed each year due to collisions with these obstructions. Data collected from these studies indicate that tall, skeletal, communication towers equipped with guy wires are one of the largest contributors to avian fatalities. Close proximity to migration routes, excessive height, and lack of conspicuity are all possible contributing factors to the avian fatalities. Research has identified the primary cause as being the steady-burning obstruction lights that attract the birds to the communication towers and cause the greatest number of avian fatalities.

Wildlife biologists and researchers have suggested that migratory birds traveling at night are the primary victims in these collisions with communication towers. Many of the small migratory songbirds tend to travel at night at low altitudes, as it offers the safest conditions for long-distance flight. Nighttime migration also offers lower temperatures, less wind and turbulence, and less danger of predators. When these small birds migrate, they typically use their natural instincts to navigate to their destination. Inclement weather or even a light fog or haze can block their view of the horizon and sky, leaving only man-made features for them to use for reference. In most instances, the birds will use bright, prominent lights that they can see in the distance as reference points, and fly to them. Unfortunately, the bright, prominent lights they select are often obstruction lights. Small migratory songbirds can become disoriented once they reach an obstruction equipped with these lights and are unable to determine in which direction to fly to their next destination. As a result, the birds tend to continue to fly around the obstruction in a state of confusion and, in some cases, fly right into the obstruction guy wires. They may also become so exhausted from flying around the tower that they fall to the ground.

Research of the avian mortality issue has indicated that the nighttime migratory birds are specifically attracted to the red, steady-burning obstruction light, referred to as the FAA-specified L-810 light fixture. Unlike flashing lights, these lights stay on constantly without flashing, providing the birds with an illuminated reference point that they use for navigation. In one comparative study conducted between 2008 and 2009 (see appendix A), it was determined that the obstructions equipped with the steady-burning L-810s caused a significantly higher number of avian fatalities than towers equipped with either white or red flashing obstruction lights. The study stated that omitting L-810s from obstruction lighting configurations could potentially reduce avian fatalities by over 70%. A copy of this report in its entirety is included in appendix A.

Avian fatalities at communication towers are a major issue for many U.S. government agencies, including the FCC, the Federal Emergency Management Agency (FEMA), and the FWS. By statute, the FCC is responsible for enforcing painting and lighting requirements for towers used for communication purposes by nonfederal entities. Currently, there are over 106,000 structures in the FCC's Antenna Structure Registration database, including more than 93,000 identified as towers, and these numbers are expected to grow. With the ongoing surge in consumer-level communication devices and the bandwidth needed by those devices (cell phones, personal data assistants, Internet access, etc.), wireless providers continue to need new towers to provide consumers with better coverage. While the majority of these wireless towers are less than 200 feet (ft), some require notification to the FAA and require lighting so as not to pose a hazard to aircraft navigation. In addition, local and state public safety agencies throughout the U.S. are developing more robust emergency communication networks, which typically require taller towers, so they will be better equipped to handle major emergency events, a lesson learned from Hurricane Katrina in 2005. To facilitate development of these networks, FEMA has issued an average of 300 grants for new tower construction each year. New tall towers may also be needed to expand or maintain radio and television broadcast coverage. In addition to the towers registered with the FCC, federal agencies are also building new towers to better advance their missions and protect the public safety. In recognition that these towers may have a significant impact on the avian population, particularly when equipped with steady-burning obstruction lights, the FCC is actively evaluating what measures may be appropriate to reduce such impacts, in the form of an ongoing rulemaking proceeding and a Programmatic Environmental Assessment.

FAA lighting and marking guidelines for obstructions are provided in FAA AC 70/7460-1 [1]. In this AC, there are provisions for using several different combinations of steady-burning or flashing red and white lights. The lighting configurations that are most commonly used throughout the U.S. are those that use either alternating aviation orange and white paint or white strobe lights for daytime protection, and a combination of flashing and steady-burning red lights for nighttime protection. These common configurations are referred to as FAA styles A, E, and F in Appendix A-1 of AC 70/7460-1. The other configurations, styles B, C, and D, all use white flashing strobe lights for both day and nighttime protection. The configurations that use the steady-burning red lights for nighttime protection are the configurations that cause the greatest impact to nocturnally migrating birds. Diagrams of these configurations, as shown in Appendix A-1 of AC 70/7460-1 are included in appendix B of this report.

While a number of FAA research projects have addressed obstruction lighting for antennas, towers, and wind turbines, no investigative research has been done that pertains to the effects of obstruction lighting on migratory birds. The guidelines that are currently in place have remained mostly unchanged for the last 10 to 20 years and have been proven sufficient for warning pilots of the presence of an obstruction. There have been isolated incidents where pilots have accidentally flown their aircraft into obstructions; however, these incidents are generally a result of the pilot ignoring minimum ceiling and visibility requirements to legally conduct the flight. The intensity, color, or flash patterns of the obstruction lights have never been cited as a causal factor in any of these incidents.

The following are the only FAA guidance documents pertaining to the lighting of obstructions:

- FAA AC 70/7460-1, "Obstruction Marking and Lighting" [1]

  This document specifically describes the various requirements for lighting and marking man-made structures as obstructions, but it makes no mention of the interaction between lighting and migratory birds.

- FAA AC 150/5345-43, "Specification for Obstruction Lighting Equipment" [2]

  This AC specifies the lighting equipment and fixtures that should be used to illuminate obstructions. The color of the light, flash rate, intensity, and various electrical and performance requirements are all addressed in this AC.

  Obstruction lights are given an "L" designation, as described in this AC. The performance characteristics for the particular lights mentioned in this evaluation are as follows:

  L-810—Red steady-burning obstruction light, 32.5 Candela at +4 to +20 degrees

  L-864—Red flashing obstruction light, 2000 peak Candela, and minimum 750 Candela, with a 3-degree vertical beam spread, flashing at a rate between 20 and 40 flashes per minute (fpm).

  L-865—White flashing strobe light, with day peak intensity of 20,000 Candela and a night peak intensity of 2,000 Candela, ±25%, flashing at 40 fpm.

- Title 14 Code of Federal Regulations, Part 77, "Objects Affecting Navigable Airspace" [3]

  This document addresses the determination of whether objects on the earth's surface constitute an obstruction to air navigation, and thus must either be prohibited or, at least, suitably marked and lighted as an obstruction.

## DISCUSSION

The results of the research conducted by wildlife biologists specifically concluded that communication towers equipped with steady-burning red lights attracted more birds and, as a result, were responsible for causing more avian fatalities than towers equipped with flashing red or white lights. In a 2008-2009 study, shown in appendix A, six towers throughout the lower peninsula of Michigan (MI), were selected to be monitored for avian fatalities. Over the course of a year, researchers physically searched the area at the base of each tower for bird carcasses, documenting the type of bird, the location, and the number found.

One structure included in this study was a television transmission tower located near Harrietta, MI, which is about 31 miles east of Lake Michigan and about 15 miles to the west of Cadillac, MI. The tower is owned by WPBN, a television station based in Traverse City, MI. It stands 1130 ft above ground level (AGL), with the tip of the tower at 2549 ft above mean sea level (see figure 1). The tower is indicated on the Green Bay Sectional Aeronautical Chart, shown in figure 2. The tower is painted in alternating bands of aviation orange and white as required by the FAA, and has 18 guy wires that support the tower (see figure 3). The tower, constructed in 1961, was the focus of a 1962 bird mortality study conducted by Dr. Larry Caldwell from Central Michigan University [4]. This study concluded that the tower was directly in the path of a major migratory flyway that hundreds of thousands of birds traveled during each migration season. Between 1962 and 1972, researchers found 2192 dead birds at the base of the tower, with the highest single night count of 692 dead birds found on September 23, 1964 [5]. In 1991, after several years of negotiation, a Special Use Permit was issued to WPBN to allow for the lighting to be switched to a nonstandard nighttime configuration in which the normally steady-burning red L-810 lights were programmed to flash simultaneously with the brighter red L-864 flashing lights.

Figure 1. The WPBN Tower, Harrietta, Michigan

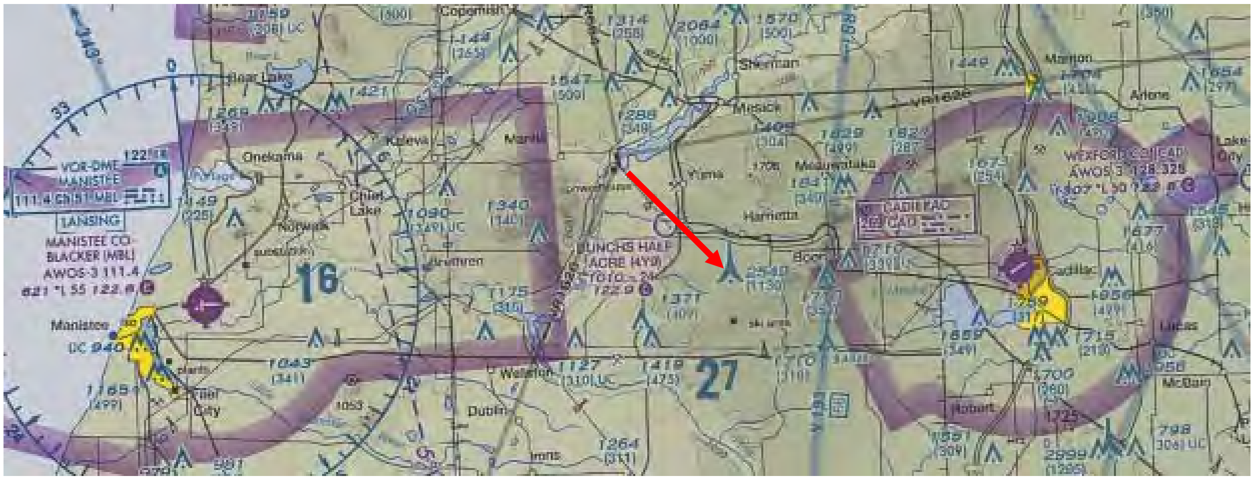


Figure 2. The WPBN Tower Indicated on the Green Bay Sectional Chart

Figure 3. Guy Wires Supporting the WPBN Tower

The lighting configuration on the WPBN tower was designed based on the results of research conducted by biologists. It was believed to be the best lighting configuration for reducing avian fatalities. At the conclusion of Dr. Joelle Gehring's study [3], the results of the avian fatalities at the WPBN tower were compared to the results of the five other towers. The results showed that the WPBN tower, without steady-burning red lights, had 70% fewer avian fatalities than towers with steady-burning red lights. The results of this study confirmed the results of other studies, which validated the theory that birds are attracted to steady-burning obstruction lights.

APPROACH.

After conducting a thorough review of the results of the studies performed at the WPBN tower, FAA researchers developed a test plan to properly evaluate the following:

- Determine the conspicuity of the nonstandard lighting configuration at the WPBN tower in Harrietta, MI.

- Determine the effects of flashing a normally steady-burning L-810 fixture.

- Determine if the steady-burning L-810 fixture could be omitted from the FAA lighting configurations for tall towers.

Researchers unanimously agreed to use the same WPBN tower used in the avian mortality study for the lighting evaluation. With cooperation from WPBN, researchers conducted flight evaluations of the nonstandard lights and, with minor modifications, had the tower reconfigured so that the L-810s were turned off completely. The tower's remote location on relatively flat land made it an optimal site for flight evaluations.

Throughout the evaluation, researchers maintained an open dialogue with the FCC, wildlife biologists and researchers, members of communication tower organizations, tower owners, and WPBN to collect feedback and comments on the suggestions presented in this research.

PROCEDURES.

The sequence of events to accomplish the flight evaluation was as follows:

1. Flight evaluation of existing communication towers to acquaint researchers with the tower characteristics and to evaluate several different obstruction lighting techniques presently in use.

2. Analysis of the flight evaluation results leading to guidelines that would potentially recommend the flashing or omission of the steady-burning red L-810 light fixtures that, when applied, would result in the most beneficial obstruction lighting configuration for minimizing bird fatalities.

3. Production of a final report providing recommendations for guidelines to be published in Advisory Circulars, if applicable.

For the current study, researchers used many of the same communication towers that were used in the wildlife study so results could be compared across the two studies. WPBN technicians adjusted the flash rate of the lights on the tower and made the necessary modifications to their electrical system to allow the L-810s to be turned on or off as needed for the evaluation. Therefore, it was possible for researchers to evaluate the proposed changes in a real-world scenario rather than using a computer simulation or duplicating the lighting configuration at another tower. In the event that the proposed changes did not perform as expected, the WPBN technicians could easily restore the lighting to its previous configuration.

FLIGHT EVALUATION OF NEARBY TOWERS.

One June 2, 2010, a flight evaluation was conducted in close proximity to the WPBN tower. Several towers to the south of the WPBN tower were included in the study. The flight team consisted of one subject pilot, two visual guidance experts, each with over 15 years of experience in evaluating visual guidance systems, and a wildlife biologist from Michigan State University. The researchers used a small general aviation aircraft, which provided slow, low-altitude flight, to observe the obstruction lighting and to take pictures during the evaluation.

During the flight evaluation, the researchers visually assessed several tall communication towers that had the following lighting configurations:

- FAA Styles A/F (figures B-1 and B-6)—a combination of steady-burning red L-810 and flashing red L-864 light fixtures on a tower approximately 1000 ft high.

- FAA Styles B/C (figures B-2 and B-3)—a series of high-intensity white strobe lights on a tower approximately 1200 ft high. Figure 4 shows this tower with the white lights illuminated.

- FAA Style E (figure B-5)—a combination of steady-burning red L-810 and a flashing red L-864 light fixtures on a cellular phone tower approximately 300 ft high.

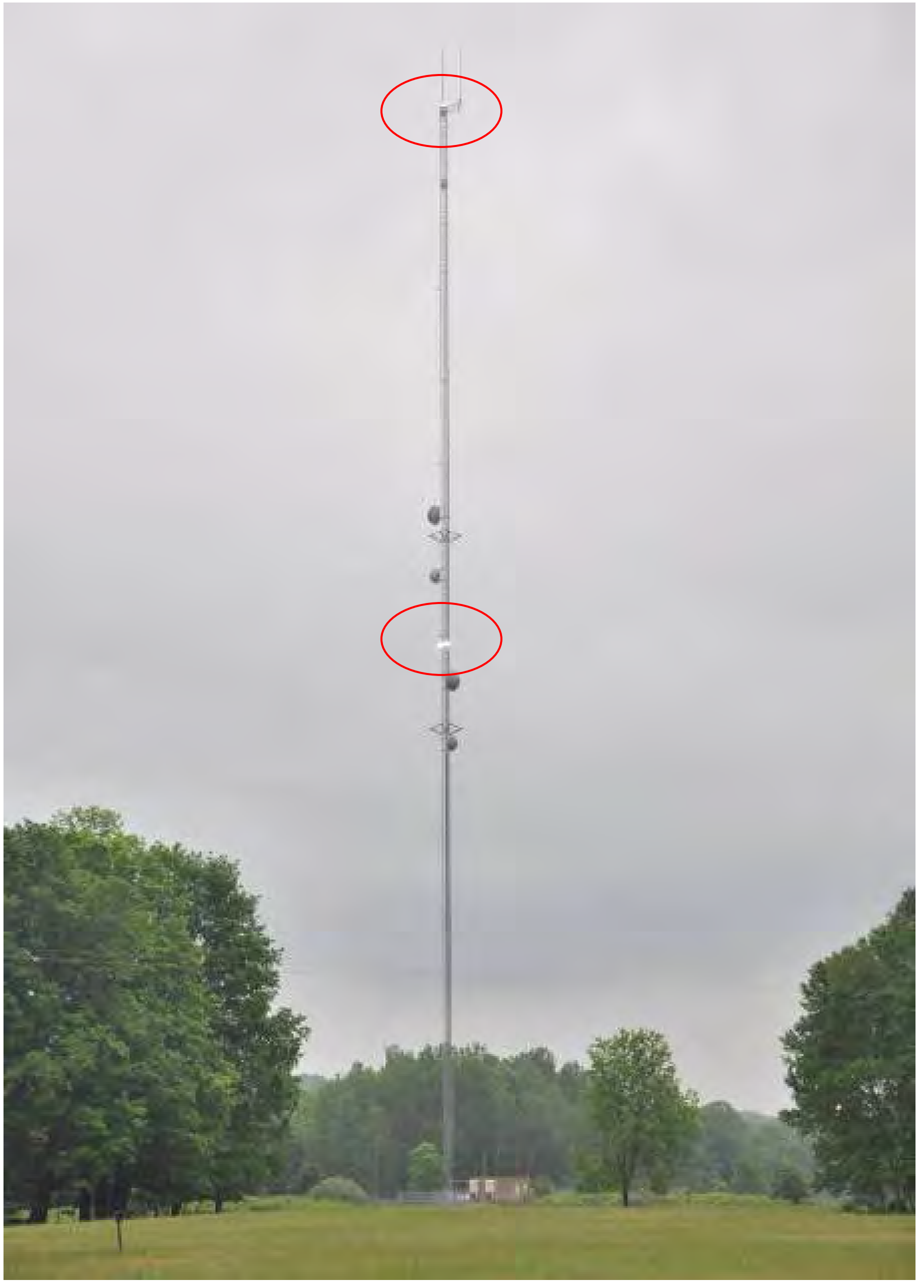

Figure 4.  A 1200-ft Tower With White Strobes

In addition to evaluating the above towers, the researchers also conducted their initial evaluation of the WPBN tower during the flight.  This tower met the requirements of FAA Style A, with aviation orange and white paint for daytime conspicuity and a combination of steady-burning red L-810 and flashing red L-864 light fixtures, but were programmed to blink at the same time. Figure 5 shows the on and off cycle of a tower illuminated according to current FAA standards, and figure 6 shows the on and off cycle for the WPBN tower illuminated with the nonstandard configuration.

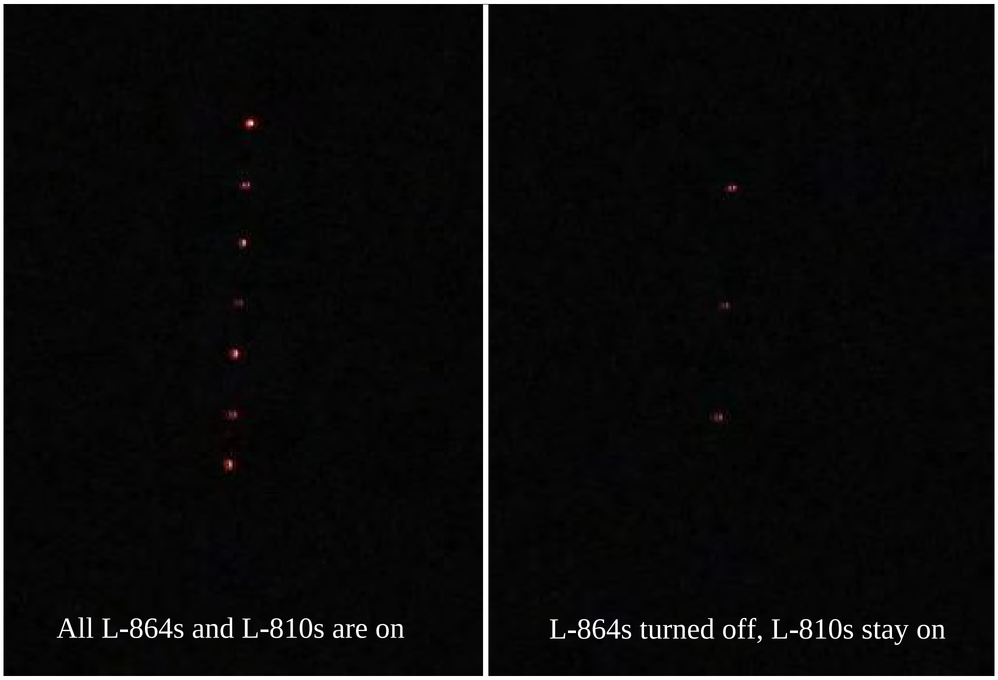


Figure 5. Current FAA Styles A/F Lighting Configuration Flash Cycle

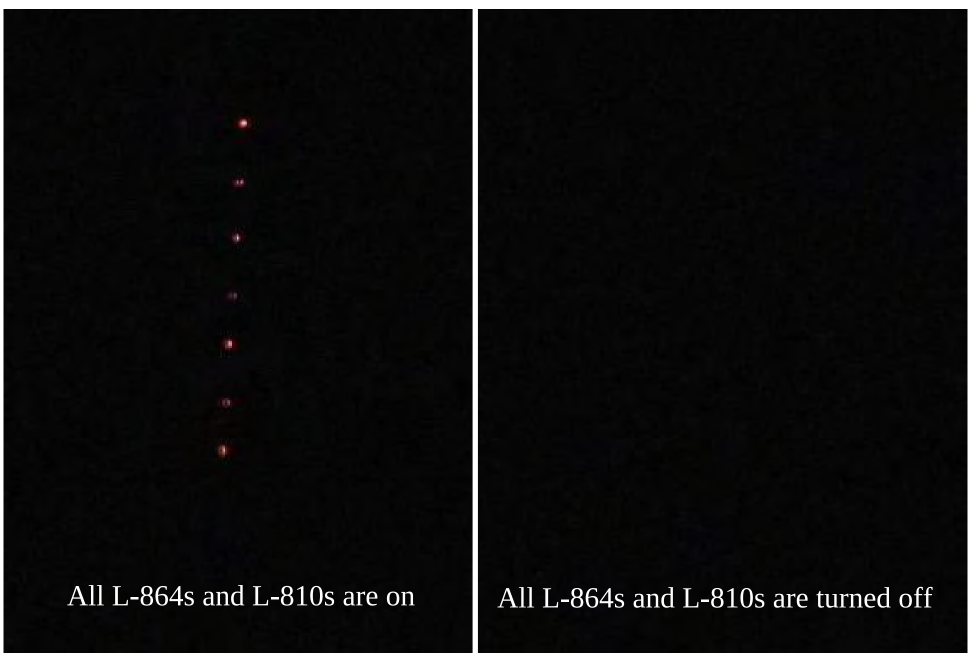


Figure 6. Nonstandard Lighting Configuration Flash Cycle on WPBN Tower

The researchers conducted a series of passes around each tower to assess each lighting configuration. This involved flights at altitudes between 500 and 1000 ft AGL, circling around the periphery of the towers to check the general layout and arrangement of the lighting on the obstructions. How the obstructions looked from distances up to 20 miles away was also observed. Photographs and video were taken during the flights.

RESULTS OF FLIGHT EVALUATION OF NEARBY TOWERS.

The researchers determined that the lighting configurations on each evaluated tower, including the WPBN tower, all provided sufficient conspicuity to provide pilots with proper warning of their presence. The assessment details of each tower are as follows:

- FAA Style A/F—a combination of steady-burning red L-810 and flashing red L-864 light fixtures on a tower approximately 1000 ft high. The flight team unanimously agreed that this particular lighting configuration was very prominent and easy to locate from more than 20 miles away, although the L-810s were not visible until approximately 10 miles away. The L-864 fixtures provided the most conspicuity. The flash rate on this tower was measured at 31 fpm.

- FAA Style B/C—a series of high-intensity L-865 white strobe lights on a tower approximately 1200 ft high. The flight team unanimously agreed that this was the most visible lighting configuration and was easily located from more than 20 miles away, but as the aircraft got closer to the tower, the lights became more distracting. The flash rate on this tower was measured at 41 fpm.

- FAA Style E—a combination of steady-burning red L-810 and a single flashing red L-864 light fixture on a cellular phone tower approximately 300 ft high. The flight team unanimously agreed that this particular lighting configuration was sufficient for locating the obstruction, but noted that the L-864 was blinking slowly enough that the L-810s became critical for locating the tower when the L-864 was in between flashes. The flash rate was measured at 20 fpm, which is the slowest flash rate allowed for this type of fixture.

- Nonstandard WPBN tower—both red L-810 and L-864 fixtures programmed to flash in unison. The tower was visible from over 20 miles away; however, the researchers were not able to differentiate the L-810 fixtures from the L-864s until they were within 10 miles of the tower. The L-810s, due to the fact they were flashing, appeared to hit peak intensity for a very brief period before they turned off. The flight team unanimously agreed that the L-864 fixtures were creating the primary warning signal, with the L-810s providing secondary warning, and that the proposed lighting configuration was sufficient for locating the obstruction.

In post-evaluation discussions, the flight team agreed that all the observed lighting configurations performed satisfactorily. The most favorable configuration was the dual use of the L-810s and L-864s (FAA Styles A, E, F, and the proposed nonstandard configuration), and the least favored was the flashing white strobe configuration (FAA Styles B/C). The flight team suggested that the proposed nonstandard configuration on the WPBN tower should be evaluated at different flash rates. It was also stated that the steady-burning L-810s become more critical in locating the tower if the L-864 flashed at a slower rate. This was evident on the 300-ft cellular phone tower because, without the L-810s, the location of the tower could be lost in between the delayed flashes of the L-864. It was determined, based on these findings, that the flash rate of the fixtures was critical, especially in the nonstandard configuration on the WPBN tower. Note, the wildlife biologist onboard the aircraft explained that the slowest flash rate for any of the lights would be the optimal setting to reduce avian attraction.

FLIGHT EVALUATION OF THE PROPOSED LIGHTING CONFIGURATION.

Based on the post-evaluation discussions concerning the proposed nonstandard lighting configuration on the WPBN tower, the researchers decided to pursue the suggestion of varying the L-810 and L-864 flash rates. The WPBN technicians adjusted the flash rates as the researchers were flying the aircraft. First, the researchers verified that the lights were flashing at their default setting of 31 fpm, after which the pilot radioed the WPBN technicians to slow the flash rate to 20 fpm (the lower limit of the flash rate range). The researchers immediately noticed a dramatic difference in the lighting presentation. Both the L-864 and L-810 lights appeared to achieve their full intensity, but there was a significant amount of off time in between flashes, which was a concern. Since all the lights were flashing at the same time, there were a few seconds in which the tower was completely dark. If the pilot was not focused on the tower, it was hard to maintain its location in between the flashes. The researchers determined that the slower flash rate was unacceptable for this configuration. The flash rate was then increased to 40 fpm, which is the upper limit of the flash rate range. Because the L-864s flashed so quickly, they only achieved full intensity for a brief period before the control signal turned it off. The L-810s, having a lower light output, were able to react faster to the control signal and were able to turn on and off faster. When compared to the slower response of the L-864, the L-810 appeared to be more attention-getting because of its faster on/off cycle. The researchers determined that this flash rate was too fast for this configuration.

During the flight, the researchers took video of the various flash rates for a side-by-side comparison. In addition, the researchers also took video of the tower through a night vision scope to verify if the proposed lighting configuration created any distractions or issues for the user. As shown in figure 7, the lighting on the WPBN tower looked no different than any other tower. In fact, researchers thought the flashing of the L-810s made the tower a bit more attention-getting though the scope because the flashing lights were clearly discernible from the background lights. It was determined that the lighting configuration did not create any unique problems when viewed through the goggles. At the conclusion of the evaluation, WPBN technicians reset the flash rate to 30 fpm.

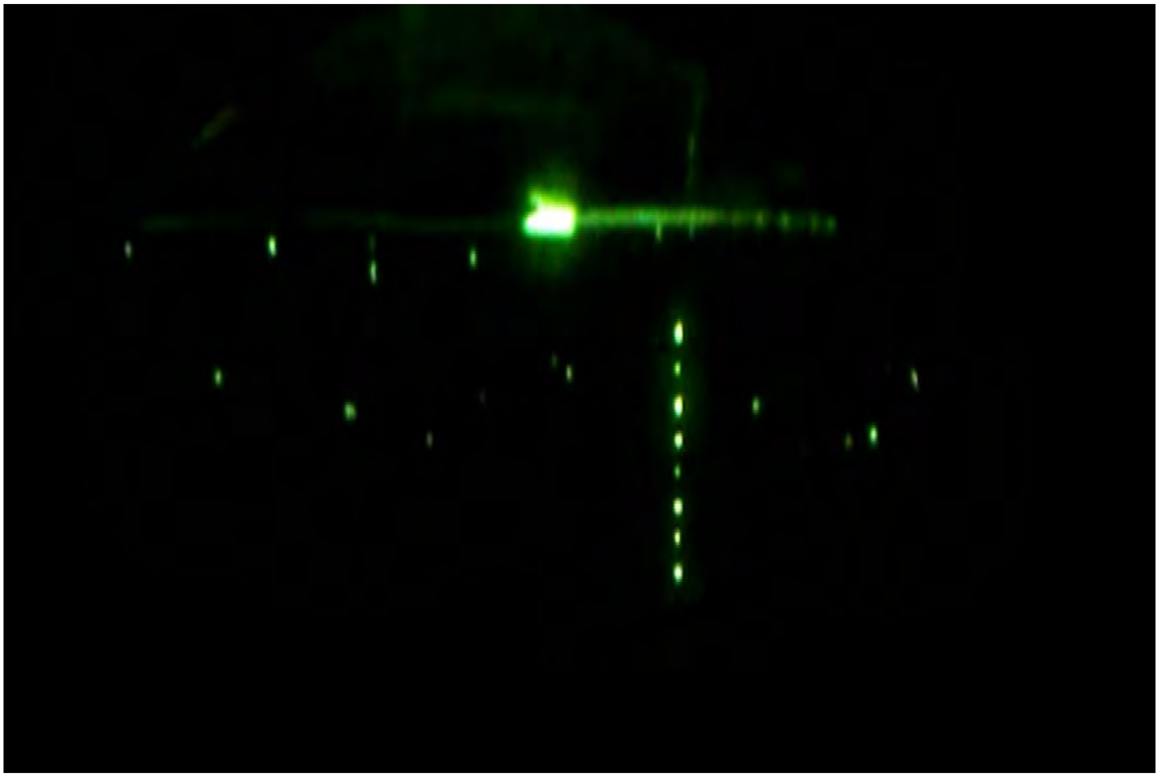

Figure 7. View of the WPBN Tower Through a Night Vision Scope

FLIGHT EVALUATION RESULTS OF THE PROPOSED LIGHTING CONFIGURATION.

The researchers determined that the proposed lighting configuration on the WPBN tower should be flashed as close to 30 fpm as possible to provide the optimal presentation to pilots. When flashed more slowly, there was too much time between flashes, making the tower dark, which could potentially be a safety issue for pilots approaching the tower. When the lights flashed more quickly, the L-864 fixtures were unable to achieve full intensity for long, which reduced the exposure time for pilots to see the lights. As a result, the L-810s were more visible from the air, as they were able to react faster to the on/off control signal, making them more noticeable than the L-864. This created an unusual visual appearance, which took away from the intent of the two very different obstruction lighting fixtures. From the results of the flight evaluation, the researchers determined that 30 fpm is the optimal flash rate, with an acceptable tolerance of ±3 flashes. In addition, the concept of flashing the L-810 in unison with the L-864 did not interfere with the night vision scope use because the intensity of the lights provided a sufficient attention-getting presentation for the night vision scope to detect.

FLIGHT EVALUATION OF PROPOSED LIGHTING CONFIGURATION WITHOUT L-810s.

With the optimal flash pattern identified, the next step was to evaluate the possible omission of the L-810s altogether. The researchers contacted the WPBN technicians to request if a switch could be installed on the tower that would allow the L-810s to be turned off without requiring any major rewiring or modification. After several weeks, the WPBN technicians installed a simple switch at the lighting control panel mounted at the base of the tower.

On September 13, 2010, the researchers returned to the site to evaluate the effects of omitting the L-810s. The same flight team was assembled and verified that the flash rate was still set at 30 fpm. Using a similar aircraft to the one used for the June 2, 2010 flight, a series of circular routes was flown around the tower. Once the researchers had sufficient time to evaluate the flashing configuration from the aircraft, they radioed the WPBN technicians at the tower to turn off the L-810s. The WPBN technicians immediately turned off the L-810s, leaving only the flashing L-864s illuminated. Figure 8 shows the difference between the FAA standard configuration and the proposed lighting configuration without the L-810s.

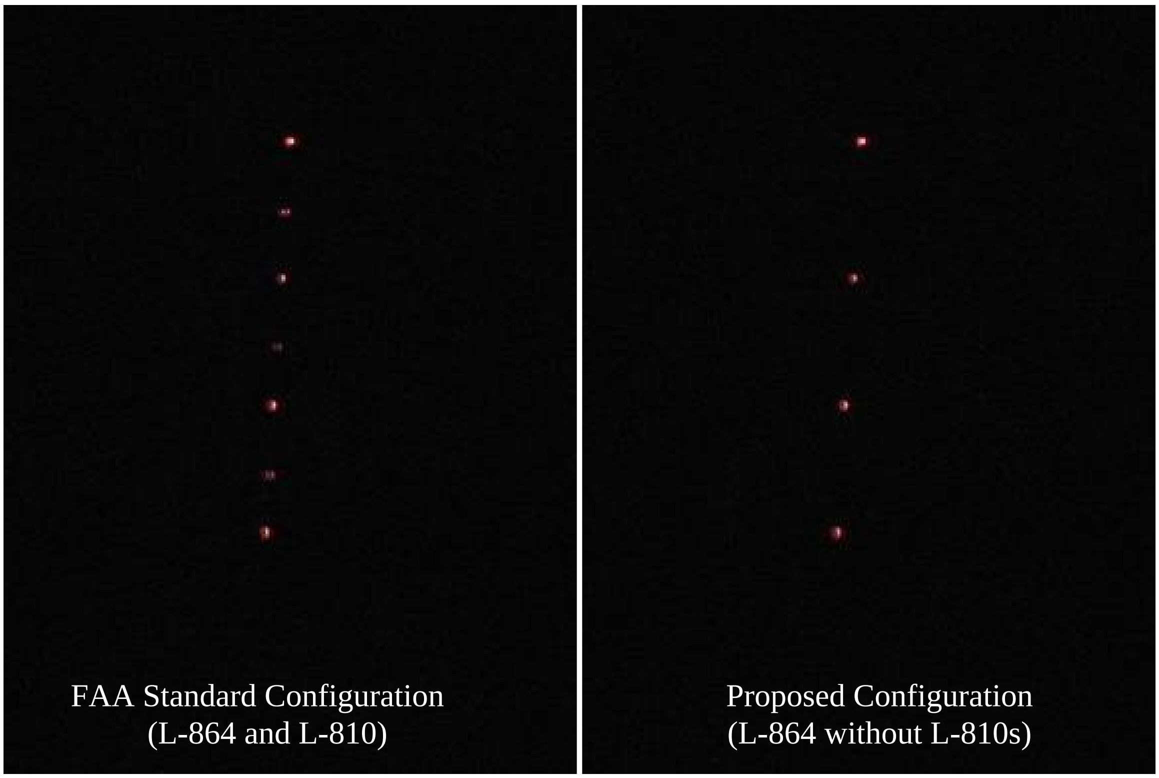


Figure 8. Comparison of FAA Standard and Proposed Lighting Configurations Without L-810s

A series of circular routes was flown around the tower while the WPBN technicians turned the L-810s on and off again. This sequence was repeated several times to allow time for researchers to assess each configuration. The researchers noted that the tower was still visible from 20 miles away, which was the same distance as in the June 2, 2010, evaluation. In addition, the 30 fpm kept the lights on long enough so the location of the tower was never lost. The omission of the L-810s did not create any unusual presentation or adversely affect the overall appearance of the lighting configuration.

The researchers also took video of the tower through a night vision scope to verify how the tower looked without the L-810s. As noted in the June 2, 2010, evaluation, there was sufficient light for the night vision scope to detect the tower without creating any distractions or problems for the user. Figure 9 shows an image of the WPBN tower without the L-810s, as observed through the night vision scope. Note how the L-864s are still very prominent in figure 9, just as they are in figure 7. The L-864s provided the most prominent light source for the night vision scope; therefore, omitting the L-810s did not adversely affect the presentation. At the conclusion of the evaluation, the L-810s were turned back on and restored to their pre-evaluation settings.

Figure 9. View of the WPBN Tower Without L-810s Through a Night Vision Scope

<u>FLIGHT EVALUATION RESULTS OF THE PROPOSED LIGHTING CONFIGURATION WITHOUT L-810s</u>.

The researchers determined that the proposed lighting configuration without the L-810s at 30 fpm provided sufficient conspicuity from the air and was considered an acceptable lighting configuration. The tower was still visible from over 20 miles away and, when flashed at 30 fpm, provided enough light so that the location of the tower was never lost. The purpose of the L-810 fixture, when used in conjunction with the L-864 lighting configuration, was to provide a point of reference for the pilot when the brighter flashes of the L-864 could not be seen. This can be overcome if the L-864 lights are flashed fast enough so the point of reference is not lost. New technologies for flasher units and for the lights themselves now allow tower owners to select a specific flash rate or flash pattern to achieve an instant and accurate result; whereas, older mechanical flasher units were not as accurate and could not be set to an exact flash rate. Based on the results of the evaluation, the researchers were convinced that the lighting configuration on the WPBN tower, without L-810s, was sufficient to be considered for inclusion into the FAA obstruction lighting standards.

INTEGRATION OF RESULTS.

The results of the flight evaluations conducted in Michigan indicate that the proposed concept of omitting the steady-burning red L-810 fixture from lighting configurations for communication towers is a viable option for reducing avian mortality and, at the same time, it preserves enough visual conspicuity for pilots to acquire and avoid the obstruction. The challenge, however, is in adopting this concept into the FAA's existing lighting styles, as described in AC 70/7460-1K. The FAA lighting standards, described as styles A, E, and F, are the three specific styles that incorporate L-810s into their lighting configurations. By adopting the proposed concept of omitting the L-810s, there are a few specific issues for each lighting style that need to be addressed. The following is a discussion of these issues with proposed solutions.

FAA LIGHTING STYLE A, RED OBSTRUCTION LIGHTING STANDARDS (as shown in figure B-1). Lighting style A is the preferred lighting configuration, as it incorporates alternating bands of aviation orange and white paint for day protection and a combination of red flashing L-864 beacons and steady-burning L-810 sidelights for night protection. For this particular lighting scheme (figure B-1), the required lighting configurations are divided into seven categories that are based on the height of the tower structure. These categories are designated A-0 through A-6, with A-0 being the lowest. The categories for towers higher than 351 ft (A-2 through A-6) have similar requirements, with additional sets or levels of L-864s and L-810s added as the height of the tower increases.

For these categories, the proposed concept of omitting the L-810s is very easy to incorporate. The most critical category of the seven is A-2 (height range between 351 and 700 ft), which has two levels of L-864s and two levels of L-810s. By applying the proposed concept of omitting the L-810s, the tower will only have two levels of L-864s. Previous aviation visual guidance research has proven that a minimum of two sets of lights is necessary to delineate an object using simultaneously flashing lights. A pilot, when exposed to at least two lights that are flashing at the same time, interprets the two lights as being connected together in some way, creating the impression that they are marking a large object, regardless of orientation (horizontally or vertically). This is apparent in lighting standards for wind turbine farms, long-span bridges, runway end identifier lights, and in-pavement runway guard lights, where the light fixtures are programmed to flash simultaneously. Flashing the two levels of L-864s simultaneously on towers between 351 and 700 ft follows this same logic.

For towers between 151 and 350 ft high (category A-1), the proposed lighting configuration creates a unique situation that does not necessarily fit the proposed concept of omitting the L-810s. These towers are only tall enough to be equipped with one L-864 at the top and one level of L-810s midway up the tower. The omission of the L-810s, in this case, would leave only one light at the top of the tower. This creates an issue in which the benefit of having two lights to define a linear obstruction is now lost. In addition, if the single lamp at the top of the tower fails, this would leave the obstruction completely unlit, making it susceptible to impact by aircraft. This could potentially create an unacceptable level of risk; therefore, three options were proposed by the researchers.

- For option 1, which was considered the easiest and lowest cost to implement, the L-810 fixtures would remain in place, but would flash in unison with the L-864 at the top of the tower. Based on the simultaneously flashing L-864 and L-810s evaluation conducted at the WPBN tower in Michigan, this configuration was found to be acceptable as long as the lights are flashed as close to 30 fpm as possible.

- For option 2, the level of L-810s would be replaced with an L-864 that flashes in unison with the one at the top of the tower. This could cause some problems for tower owners because the L-864 is a much larger fixture and may not be as easy to mount as the L-810s.

- For option 3, a second L-864 would be installed at the top of the tower that could be programmed to turn on if the primary L-864 fixture failed. There are problems with this option as well. First, it does not provide the two lights that are necessary to define a linear obstruction. Second, the fixture would add weight to the top of the tower. Third, finding a position at the top of the tower where it would not be in the way of the light from the primary L-864 would be difficult. This would likely require the fabrication of a complex bracket that would place one fixture on top of the other, the cost of which would be incurred by the tower owners, and it would add additional weight and wind load to the tower.

The researchers recommend option 1 because it makes use of the fixtures that are already there and would only require minor rewiring to connect the light circuits together to make the L-810s flash with the L-864. The FAA would be required to modify the standard for the L-810 to include the provision that it can be flashed at the same rate and duration as the L-864.

Towers under 150 ft high (category A-0) that only require a single set of steady-burning L-810s would not be affected by this proposed change. Data collected from wildlife studies indicate that most migratory birds do not fly below 150 ft; thus, these towers do not pose the same problem as the taller towers. In addition, towers less than 150 ft do not typically require guy wires, and they blend in with other buildings, terrain, or other man-made obstructions. This sized obstruction is not a major risk for birds or airplanes. The researchers were concerned that one flashing L-810 would not be sufficient to use as a primary warning light on an obstruction; as a result, they proposed that the lighting requirements for this height category remain unchanged.

A revised diagram showing the proposed lighting configurations for FAA style A (categories A-0 through A-6) is shown in figure C-1 in appendix C.

FAA LIGHTING STYLE E, MEDIUM-INTENSITY, DUAL-OBSTRUCTION LIGHTING STANDARDS (as shown in figure B-5). Lighting style E is a common lighting configuration that is designed for towers under 500 ft, using medium-intensity L-865, white, flashing strobe lights for day and twilight protection and both red flashing L-864 and steady-burning L-810s for night protection. Painting the tower is not required for daytime conspicuity. For this particular lighting configuration (figure B-5), the required lighting configurations are separated into two different categories based on the height of the tower structures. Category E1 includes towers between 200 and 350 ft, and category E2 includes towers between 351 and 500 ft.

For lighting style E, the proposed concept of omitting the L-810s for night protection can be incorporated almost identically to categories A-1 and A-2 (lighting style A). This would address the same issues researchers identified in regard to needing a minimum of two lights to delineate a linear obstruction, as well as the concerns for swapping the L-810s for a larger, heavier L-864 fixture. For category E-1, it was recommended that one level of L-810s be programmed to flash at the same time as the L-864 at the top of the tower. For category E-2, it was recommended that both levels of steady-burning L-810s be omitted, leaving the set of L-864s at the midpoint of the tower and the L-864 fixture at the top of the tower flashing simultaneously. This proposed concept would not impact the daytime lighting requirements of lighting style E because the combination of red flashing L-864 and white strobe L-865 fixtures that are typically used for this lighting style would remain at the same height on the tower. The only change is the omission of the steady-burning L-810 fixtures.

A revised diagram showing the proposed lighting configurations for FAA lighting style E (categories E-1 and E-2) is shown in figure C-2 of appendix C.

FAA LIGHTING STYLE F, HIGH-INTENSITY, DUAL-OBSTRUCTION LIGHTING STANDARDS (as shown in figure B-6). Lighting style F is the most common dual-lighting configuration used for night protection of tall communication towers, because it does not require painted bands of aviation orange and white for daytime conspicuity. These paint bands can be very expensive to maintain over a long time period; therefore, many tower builders chose this lighting style because it is cheaper to install and maintain additional light fixtures over time versus repainting the tower every few years. This configuration complements lighting style E, as it is designed for towers that are over 500 ft. Towers that are above 500 ft are required to upgrade from medium-intensity, white strobe lights (required in lighting style E for day protection) to high-intensity, white strobe lights (L-856) required in lighting style F. Lighting style F covers towers from 500 to 2200 ft. For this particular lighting configuration (figure B-6), the required lighting configurations are divided into five different categories based on the height of the tower structures. With the exception of the day protection being upgraded to the L-856 white strobes, lighting style F uses the same combination of red flashing L-864 and steady-burning L-810s for night protection as lighting style E. The first category, F-2, includes towers between 501 and 700 ft, using two levels of L-864s and two levels of L-810s. Categories F3 through F6 use the same lighting configuration as F-2 with another level of L-810s and L-864s added to each category.

The proposed concept of omitting the L-810s for night protection can be incorporated almost identically to lighting style A categories A-2 through A-6. For categories F-2 through F-6, it was recommended that the levels of steady-burning L-810s be omitted, and that all the remaining sets of L-864s continue to flash simultaneously. As noted for lighting style E, the high-intensity white L-856 strobes required by style F for daytime protection would be unaffected.

A revised diagram showing the proposed lighting configurations for FAA lighting style F, categories F-2 through F-6, is shown in figure C-3 in appendix C.

USING LED LIGHTING TECHNOLOGY.

Throughout this research effort, the researchers paid close attention to towers that use either LED or rapid discharge lighting technology for their obstruction lighting. These types of fixtures, which feature an instant on and off capability, offer improved conspicuity over traditional incandescent fixtures because of their rapid flashing action. Incandescent lamps have a tendency to be slow in turning on and off due to the time it takes for the filament inside the light fixture to either warm up when turned on or cool down when it is turned off. This slow warming and cooling time gives the appearance of a lazy flash pattern. In some situations, where an incandescent light fixture is being flashed at a faster flash rate (between 35 and 40 fpm), the filament of the light fixture cannot cool completely before it is energized again to complete the next flash cycle. Essentially, the light never completely turns off. Wildlife biologists believe that migratory birds will still fixate on these lights even if they change intensity during the flash cycle. As long as there is some light available, the birds will focus on it for navigation. For this reason, it is very important that the lights used on obstructions go completely off during a flash cycle. LEDs and other types of rapid discharge lighting fixtures offer this benefit.

In addition to their unique flash pattern, LEDs also offer the benefit of longer life expectancy over incandescent lights, as well as better resistance to various noise and wind vibration that typically has a negative effect on incandescent obstruction lights. In the proposed configurations where the L-810s are flashed simultaneously with the L-864, LED fixtures may be the optimal type of light for ensuring that the two lights flash at the same time, despite their differences in size and intensity. Their ability to turn on and off instantly at the same time greatly enhances the intended presentation of the new proposed lighting configurations.

## CONCLUSIONS

After completing this multiphase evaluation, it was determined that the proposed concept of redefining the standards for obstruction lighting for communication towers to omit steady-burning lights may be a viable concept that the Federal Aviation Administration (FAA) should strongly consider implementing. The researchers were able to prove through flight tests and evaluation of several different obstruction lighting configurations that the L-810 fixture can be omitted or flashed to reduce their impact on migratory bird mortality, and still provide sufficient conspicuity for pilots to see and avoid the obstruction. This concept supports the efforts of the Federal Communication Commission (FCC) and Federal Emergency Management Agency (FEMA) to address the impact that communication towers will have on migratory birds, as well as the recommendations of several wildlife research and conservation organizations.

Details of these conclusions are as follows:

1. The nonstandard lighting configuration used on the WPBN television tower in Harrietta, MI, provided sufficient conspicuity for pilots and, furthermore, the nonstandard lighting

configuration on the WPBN tower could be further enhanced by omitting the steady-burning L-810s from the lighting configuration altogether, in an effort to further reduce avian attraction.

2. A steady-burning L-810, if flashed at 30 fpm simultaneously with a flashing L-864, provided sufficient light output to contribute to the overall lighting configuration on the tower, giving pilots adequate information that the lights are marking a linear obstruction. Thirty flashes per minute (±3 flashes) was determined to be the optimal flash rate for flashing the red warning lights (L-810 and L-864) on communication towers.

3. The concept of omitting the L-810 from lighting configurations is a viable option for towers that would normally require at least two levels of red flashing L-864 fixtures. For those towers that normally require only one red flashing L-864 and one level of steady-burning L-810s, it would be necessary to flash one level of L-810s simultaneously with the L-864 to provide sufficient lighting to mark the obstruction. Smaller towers that normally require a single set of steady-burning L-810s would remain unchanged.

4. Current FAA obstruction lighting standards could be modified or redefined without major issue. The details of the changes required are as follows:

   a. FAA Advisory Circular (AC) 150/5345-43, “Specification for Obstruction Lighting Equipment,” will need to include a provision for the L-810 fixture to be flashed with the same flash characteristics as the red-flashing L-864 fixture, as provided in Table 4 of the AC. All photometric characteristics for the L-810 should remain unchanged. Provisions should also be made to further restrict the flash rate of the L-864 and L-810 to 30 flashes per minute (±3 flashes) when used specifically on communication towers.

   b. FAA AC 70/7460-1K, “Obstruction Marking and Lighting,” will need to include the provisions of flashing L-810s simultaneously with L-864s on the towers described as FAA lighting style categories A-1 and E-1. For all other FAA lighting styles that previously included L-810 fixtures (categories A-2 through A-6, E-2, and F-2 through F-6), changes will need to be made to omit the requirement for the L-810, so long as the remaining L-864 fixtures flash simultaneously at 30 fpm (±3 flashes). Adherence to this optimal flash rate is critical to providing sufficient conspicuity in the absence of the steady-burning lights and to reduce the attraction of migratory birds.

5. Light-emitting diode (LED) and other types of rapid discharge light fixtures provide a more attention-getting signal for illuminating obstructions compared to incandescent light fixtures. The near-instant on and off characteristics of LEDs make them easier to locate from greater distances, and allow the precise control of the flash rate and synchronous operation with other fixtures. The pronounced off cycle of LED fixtures would make them less attractive to birds.

A series of guidelines was developed for understanding the proposed changes presented in this report. These proposed changes are presented as an option to the FAA standard to reduce the impact of tower lighting configurations on migratory birds. It was not necessarily proposed as a complete redefinition of all FAA lighting standards. These proposed guidelines are included in appendix C.

## REFERENCES


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APPENDIX A—AVIAN COLLISION STUDY

**Studies of avian collisions with communication towers: a quantification of fatalities at a self-supported Rescue 21 tower and a test of different tall tower lighting systems**
**2008 and 2009 Progress Report**


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15 April 2010

MICHIGAN STATE UNIVERSITY EXTENSION

**Executive Summary**

Since the late 1960s researchers have documented avian collisions with communication towers. Their findings suggest that birds, primarily night migrating, neotropical songbirds, are attracted to communication tower lights during inclement weather and then collide with the tower structure or the guy wires supporting the tower. The United States Fish and Wildlife Service (USFWS) conservatively estimates that 4-50 million birds collide with communication towers every year in the United States (Manville 2005). It is likely that the siting or location of a communication tower in relation to avian migratory pathways and bird concentration areas is related to the frequency of avian collisions. In addition, past research suggests that tower lighting systems are also related to the frequency of avian collisions (Gehring et al. 2009). The objectives of this ongoing study are to quantify the frequency of avian collisions at a tower constructed in an area believed to have high intensities of songbird migration and to compare the frequency of avian fatalities at tall towers > 277 m Above Ground Level (AGL) which are lit with different lighting systems. In the spring and fall of 2008 and 2009 this study determined that that the self-supported, United States Coast Guard (USCG) Rescue 21 tower studied was not involved in frequent avian collisions despite its' location in coastal Cape May, NJ, an area documented to have large and frequent influxes of migratory songbirds. This is likely due to its self-supporting design compared to a guy wire supported design. Future research at this site would benefit from inclusion of radar ornithology techniques or acoustical monitoring to document the presence of songbirds in the area and their response to the lit tower during their migration. In the spring and fall of 2008 and 2009 I also compared the numbers of avian fatalities at 6 Michigan communication towers > 277 m AGL lit at night with 3 different lighting systems. Technicians and I found significantly more avian fatalities at the towers lit with both red blinking lights and red non-blinking than at towers lit with white strobe lights or with only red blinking lights. Although it is not possible to reduce avian collisions by changing the location or the support system of an existing tower, this research once again documents that changing a tower's lighting system can reduce avian fatalities by more than 70 %. This research is an important step in the process of reducing avian collisions at communication towers.

## Introduction

For decades researchers have documented avian fatalities at lit towers. Their findings suggest that birds, primarily night migrating, neotropical songbirds, are either attracted to or disoriented by communication tower lights, especially when night skies are overcast, foggy, or when there is precipitation (e.g., Avery et al. 1976, Caldwell and Wallace 1966, Cochran and Graber 1958). Upon flying in close proximity to the structure, birds are vulnerable to collisions with the tower structure or the guy wires supporting the tower. Previous research has demonstrated higher frequencies of avian fatalities at towers supported by guy wires than at self-supported towers and higher frequencies of collisions at towers > 277 m AGL compared to shorter towers (Gehring et al. in review).

Researchers have also documented that the type of tower lighting system can be related to the numbers of avian collisions. Specifically, Gehring et al. (2009) found significantly more avian fatalities under towers 116-146-m AGL that were lit at night with systems that included non-blinking, red lights than at towers lit with only blinking lights. Gauthreaux and Belser (2006) used a marine radar to demonstrate that more night migrants flew in circular flight patterns near a guyed communication tower (>305 m AGL) with red blinking lights combined with red non-blinking lights than near a guyed tower of similar height equipped only with white strobe lights. Similarly, a study by Kerlinger et al. (in review) at several wind power installations showed that there was no detectable difference in avian fatality rates between wind turbines marked with red blinking lights and turbines with no lights. Although we have documented the relationship between tower lights and avian collisions, researchers have not had the opportunity to test the importance of light systems on tall towers (> 277 m) to the frequency of avian collisions. Considering that taller towers are closer to the migration altitude of songbirds and inherently involved in more collisions, it could be suggested that light system changes would not be as effective in preventing collisions when compared to light system changes on towers 116-146 m AGL.

The location or siting of a communication tower is also believed to be related to the frequency of avian collisions. Towers located near areas of intense bird migration, such as coastal areas or peninsulas of land adjacent to large water bodies, are thought to cause more avian fatalities than towers in areas with lower bird migration intensities. However, very few data exist regarding the relationship between bird migration intensities and collisions with communication towers.

The objectives of the study are to:

1. quantify the frequency of avian collisions at a tower constructed in an area believed to have high intensities of songbird migration. (Part I)

2. compare the frequency of avian fatalities at towers > 277 m AGL which are lit with different lighting systems. Specifically, towers lit with red blinking lights combined with non-blinking lights will be compared to towers lit with blinking white strobe lights compared to towers lit with only blinking red lights (Part II).

The study of these issues will allow us to site new communications towers more appropriately to avoid avian collisions. In addition, we can better understand the relationship between tower lighting systems and avian collisions and potentially alter existing communication towers to reduce those collisions. This report summarizes the results of the 2008 and 2009 field seasons.

## Part I. The quantification of avian collisions with a self-supported Rescue 21 tower located in an area of high migratory bird densities

### Study Area and Methods

Research was conducted at an unguyed USCG Rescue 21 communication tower 107 m (350 ft) AGL located on the Training Center Cape May (TRACEN), in Cape May, New Jersey (Fig.1). This area has been documented as a concentration area for night migrating, neotropical songbirds (www.birdcapemay.org/morningflight.shtml). The Rescue 21 tower system provides contemporary and reliable command, control, and communication abilities to further enhance the USCG abilities to accomplish their mission of search and rescue, as well as Maritime Homeland Security. The tower was lit at night with blinking red strobe lights at the top level and mid level and also with non-blinking, red lights at the midpoints between the top-level and mid-level strobes and between the mid-level strobe and the ground (Fig. 2).

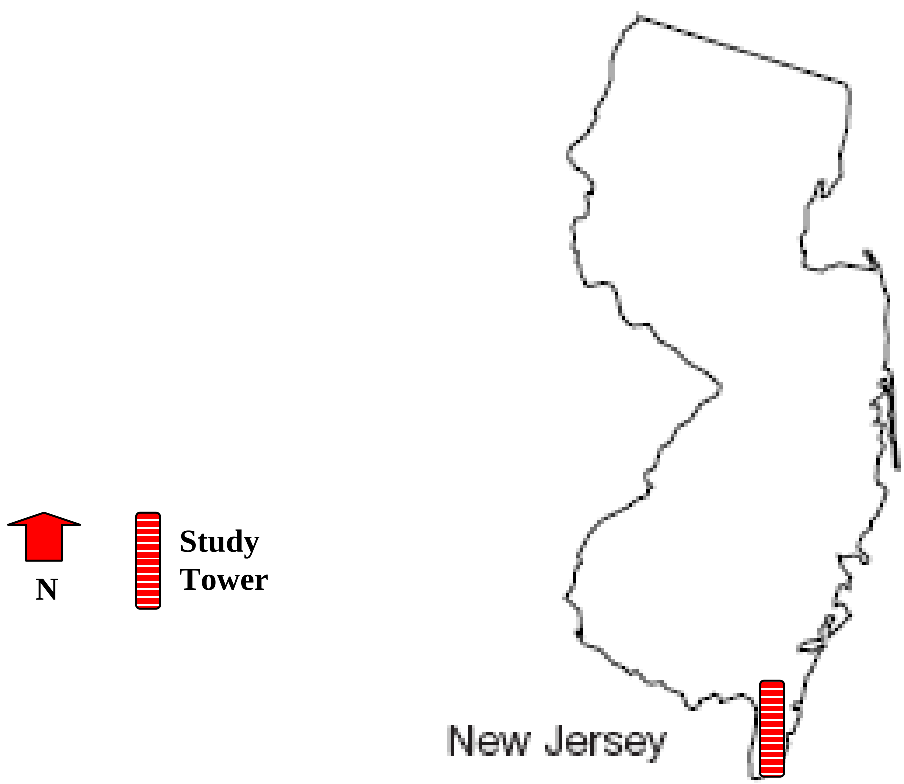



Figure 1. A Cape May, NJ United States Coast Guard Rescue-21 tower was the focus of a study on avian collisions in May and September 2008 and 2009. The coastal location of the tower likely increases its potential for avian collisions.

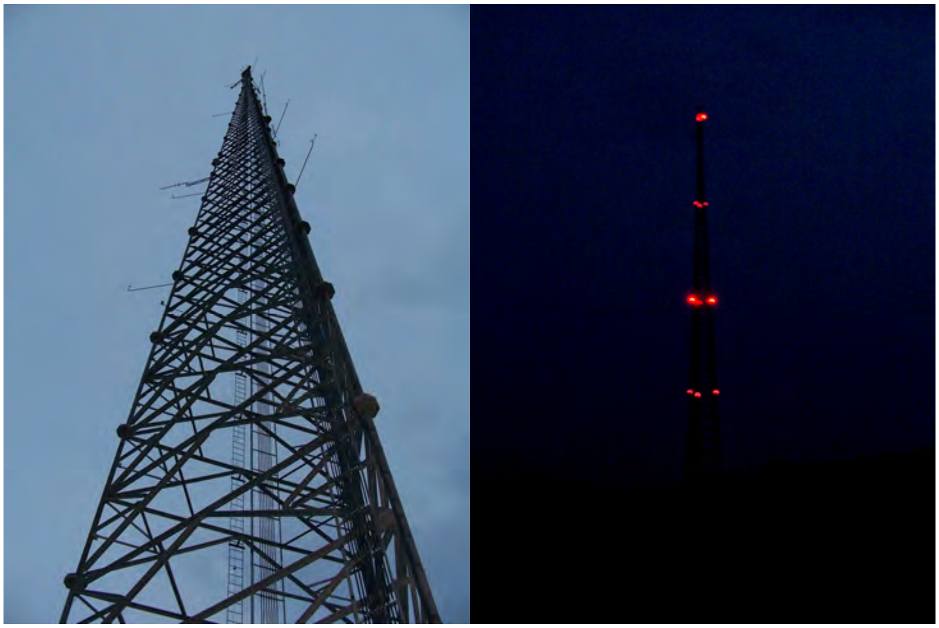


Figure 2. A Cape May, NJ United States Coast Guard Rescue-21 tower was the focus of a study on avian collisions in May and September 2008 and 2009. The nighttime lighting system on this unguyed, lattice-structure was blinking red strobe lights at the top level and mid level (appearing bright in the photo); with non-blinking, red, incandescent lights at the midpoints between the top-level and mid-level strobes and also at the midpoints between the mid-level strobe and the ground (appearing dim in photo).

**Carcass searches**

The tower was searched 7-26 May and 11-30 September, 2008 and 7-26 May and 11-30 September, 2009. After onsite training, the technicians arrived at the tower as early in the day as possible in an effort to prevent diurnal and crepuscular scavengers from removing carcasses. Using flagged, straight-line transects, the technicians walked at a rate of 45-60 m per min and searched for carcasses within 5 m on either side of each transect (Fig. 3, Gehring et al. 2007, Erickson et al. 2003). Transects covered a circular area under the tower with a radius of 90% of the height of the tower. Bird carcasses were placed in plastic bags, and the following data were recorded: tower identification number, date, closest transect, distance from tower, azimuth to the tower, estimated number of days since death, and observer's name. Once bagged and labeled, carcasses were frozen for later identification and verification of species. I maintained the appropriate USFWS and New Jersey Department of Environmental Protection- Division of Fish and Wildlife permits for collection of bird carcasses.

Figure 3. A Cape May, NJ United States Coast Guard Rescue-21 tower was the focus of a study on avian collisions in May and September 2008 and 2009. Flags were systematically placed within the search area to facilitate methodical searches for avian carcasses.

**Observer detection and carcass removal trials**

It is unlikely that technicians observe all bird carcasses under communication towers. This is in part due to dense vegetation, observer fatigue, human error, and scavenging by predators. Therefore, the technician's observer detection rate and the rate at which carcasses were removed were quantified each field season (Erickson et al. 2003). Technicians were not notified when the observer detection trial would occur, or how many and what species of bird carcasses would be placed at their tower site. Mr. Christopher Hajduk, Chief of the Environmental Protection and Safety Section at TRACEN, assisted with observer detection trials by placing 10 Brown-headed Cowbird (*Molothrus ater*) carcasses within the tower search area each study season. I was then able to quantify the proportion of bird carcasses detected by the technician. For these detection trials I painted the Brown-headed Cowbirds to simulate the plumage of migrating songbirds. Bird carcasses used for observer detection trials were also painted with an "invisible" paint that glowed fluorescent colors when viewed under a black light. When analyzing the study data, the "invisible" paint prevented any confusion between birds that had collided with the towers and birds placed in the plots for observer detection trials.

Similarly, the technician placed 15 bird Brown-headed Cowbird carcasses immediately adjacent to the edges of the communication tower's search area and recorded the removal (e.g., scavenging) of carcasses daily during the study period of each migration season. Using these data, I calculated a scavenging or removal rate (Erickson et al. 2003). Bird carcasses used in the removal trials were not painted, as this foreign scent might have influenced the removal of carcasses by scavengers. Both observer detection trial birds and removal trial birds were placed in a range of habitats characteristic of the individual tower search area.

**Statistical analyses**

Using methods developed by W. Erickson (WEST, Inc.), I used the observer detection rate and the carcass removal rate specific for each field season to calculate adjustment multipliers by which to correct the observed number of birds at the tower each season. This adjustment method considered the probability that carcasses not found on one day could be found on the following days, depending on the rate of carcass removal (W. Erickson pers. comm.). These two interacting variables were used to determine an average carcass detection probability and the related adjustment multiplier specific to each tower.

**Results**

During the two study seasons of 2008 the technician found 1 unknown sparrow determined to be killed during the study. In 2009, technicians found 3 and 5 in spring and fall, respectively (Table 1). Because 50% of the search area was inaccessible due to impenetrable poison ivy, it's necessary to make appropriate adjustments to the estimates of carcasses detected by multiplying the number of carcasses by two.

Table 1. The numbers of bird carcasses found at the Rescue 21 communication tower during the spring and fall of 2008 and 2009.

| **Migration season** | **Number and species of carcasses found** [a, b] | **Multiplier** |
|---|---|---|
| Spring 2008 | 1 | 1.9 |
| Fall 2008 | 0 | 1.5 |
| Spring 2009 | 3<br>Sora, unknown small bird, unknown large bird | 2.9 |
| Fall 2009 | 5<br>Sora, unknown small bird, 2 unknown medium birds, Yellow-bellied Flycatcher, | 1.2 |
| **Total** | **9** | — |

[a] all names of birds follow the *AOU Check-list of North American Birds*

[b] bird carcass heavily scavenged preventing identification of species

The observer detection rates for the spring and fall 2009 were 0.4 and 0.8, respectively. The carcasses removal rate was 12.4 days and 13.6 for spring and fall 2008, respectively, and 7.1 and 6.0 in 2009. I used the observer detection rate and the carcass removal rate specific for each survey season to calculate adjustment multipliers by which to correct the observed number of birds. The carcass detection probability specific to this tower was 1.9 for the spring and 1.5 for the fall 2008 and 2.9 and 1.2 for 2009 (Table 1).

**Discussion and objectives for the Rescue 21 tower study in 2009**

The low levels of avian fatalities documented at this communication tower are supported by past research in Michigan where we found a mean of 0.5 bird carcasses per self-supported tower of similar height each migration season, independent of the tower lighting system (Gehring et al. in review). It is likely that migratory songbirds are attracted to the site, however, are not colliding in detectable numbers due to the lack of guy wires. Based on past research, significantly more avian fatalities would occur had the USCG constructed a guyed tower instead of an unguyed structure (Gehring et al. 2007). It is important to note that birds do still occasionally collide with this structure. In the summer of 2008 (not during the study period) a Peregrine Falcon (*Falco peregrinus*) collided with tower and was killed (C. Hajduck, personal communication). These data are very valuable for future tower construction and development, especially in areas with large concentrations of night migrating songbirds.

While self-supported towers do not appear to be involved in high levels of avian fatalities it is possible that night-migrating songbirds are diverting from their migration path as they are attracted to the tower lights. The energy used in this behavior could potentially be detrimental to the ultimate success of an individual bird's migration. For example, it is necessary for some songbirds to fly for 3-4 days at a time without refueling while traversing large bodies of water, depending only on body fat for survival. If their available body fat has been reduced unnecessarily while attracted to lit structures it could potentially decrease their likelihood of surviving later during critical periods of migration. Considering that there are >100,000 communication towers in the United States alone, there is potential for an individual bird to spend considerable time and energy on behaviors not useful for migration and this behavior could ultimately result in indirect mortality. Alternate methods of research would be necessary to document the attraction of night-migrating songbirds to a lit self-supported communication tower.

I was not able to secure a radar system in 2008 to conduct radar ornithology at the TRACEN USCG Rescue 21 communication tower site. I am currently exploring the possibility of using night vision technology or acoustical monitoring to accomplish what I had hoped to accomplish using radar ornithology. First, we could document the presence or absence of night-migrating songbirds at the site, despite the lack of fatalities; thereby, potentially adding additional insight into the use of self-supported towers to prevent avian collisions. Second, we could examine the prediction that birds are diverted from a direct migration path in response to the communication tower lights.

Similar to 2007, the data collected in 2008 and 2009 suggest that by investing in a more expensive, self-supported communication tower at this site, the USCG Rescue 21 system has successfully avoided significantly contributing to the 4-50 million birds estimated to collide with communication towers each year in the United States (Manville 2005). Additional data collection will not only provide study replication to ensure that the study's findings are consistent from year to year but will also further our knowledge of the issue of avian interactions with communication towers and possibly contribute to creative methods whereby to reduce the frequency of fatalities at a national scale.

## Part II. The frequency of avian collisions with tall communication towers: a comparison of tower light systems

### Study Area and Methods

Research was conducted at 6 communication towers distributed throughout the lower peninsula of Michigan, USA. Towers > 277 m AGL were selected based on granted access by tower owners, existing tower lighting systems, and their dispersion throughout the study area (Fig. 5). Towers located within 1.6 km of an extensively-lit area (e.g., large urban area) or within a tower farm (additional communication tower(s) within 0.81 km) were not included in the study. This procedure prevented a situation where communication tower lights might be less visible to birds or "washed-out" due to sky glow in the surrounding areas (Caldwell and Wallace 1966). I was granted access to two towers lit at night with red blinking lights (L-864) combined with red non-blinking lights (L-810), three towers lit at night only with white strobes (L-865) and no non-blinking lights, and one unique tower with red blinking lights (L-864) combined with L-810 lights reprogrammed to blink simultaneously with the L-864 lights (Fig. 6). The first two lighting systems described meet the recommendations of the FAA (FAA 2000). The last lighting system described does not currently meet the recommendations of the FAA but was provided a lighting variance by the FAA as part of a Special Use Permit on United States Forest Service land. Mr. Christopher Schumacher of the Huron-Manistee Ranger Station requested this light change in an effort to possibly reduce bird collisions.

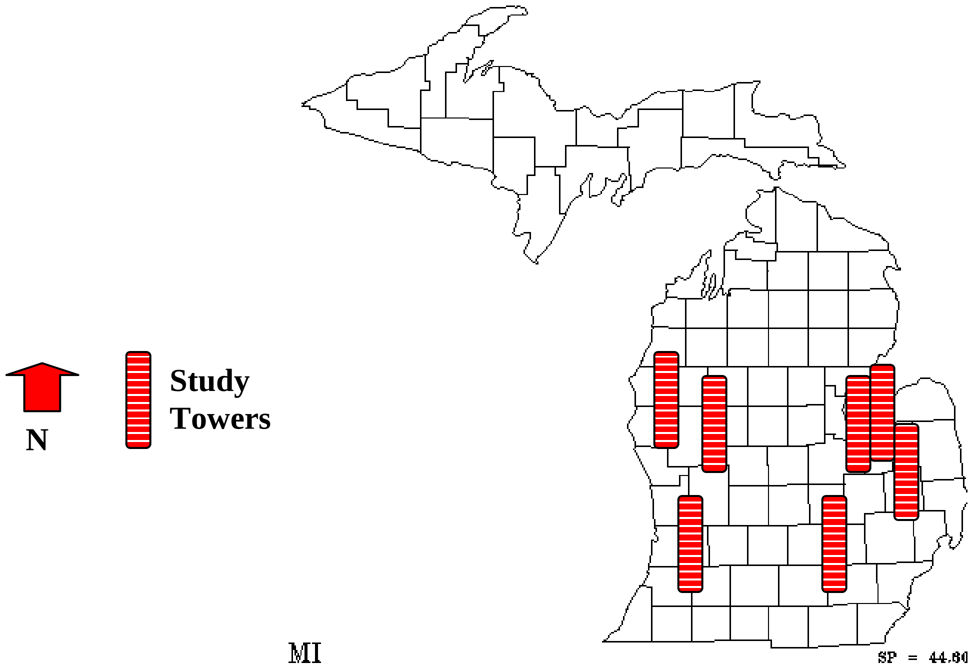
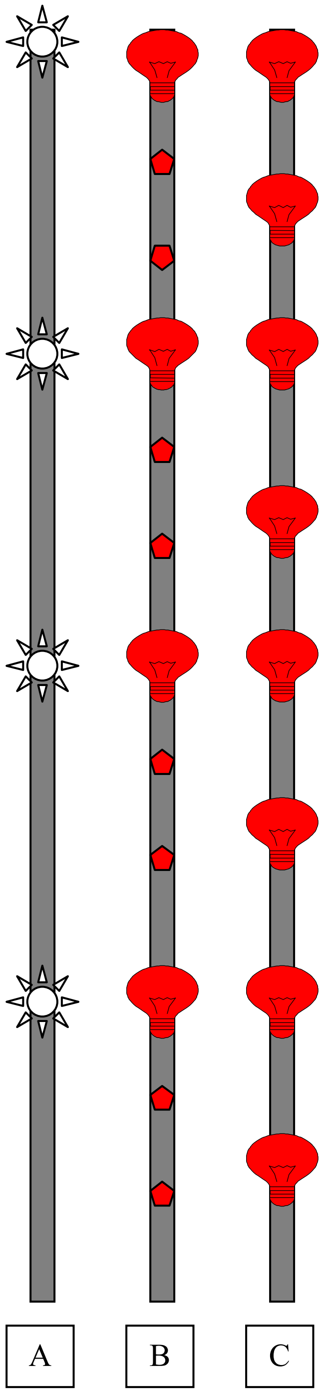



Figure 5. Seven communication towers located throughout the lower Peninsula of Michigan were included in a study of avian collisions (six each season). The areas under these towers were simultaneously and systematically searched for bird carcasses during 20 consecutive mornings surrounding the peak of songbird migration in the spring and fall 2008 and 2009 to compare the relationships between avian fatalities and tower lighting systems.




A. 3 guyed towers > 277 m AGL with white blinking strobe lights (L-865) at multiple levels; no non-blinking lights

B. 2 guyed towers > 277 m AGL with red blinking incandescent lights (L-864) at multiple levels alternating with non-blinking incandescent lights (L-810)

C. 1 guyed tower > 277 m AGL with red blinking incandescent lights (L-864) multiple levels and no non-blinking incandescent lights (L-810)

Figure 6. Three communication tower lighting systems were compared on 6 towers > 277 m Above Ground Level. The areas under these towers were simultaneously and systematically searched for bird carcasses during 20 consecutive mornings surrounding the peak of songbird migration in the spring and fall 2008 and 2009 to compare the relationships between avian fatalities and tower lighting systems.

## Carcass searches

Towers were searched 10-29 May and 7-26 September, 2008 and 2009. Searching the same tower every day, technicians arrived at the towers as early in the day as possible in an effort to prevent diurnal and crepuscular scavengers from removing carcasses. Using flagged, straight-line transects, technicians walked at a rate of 45-60 m per min and searched for carcasses within 5 m on either side of each transect (Gehring 2004, Erickson et al. 2003). Transects covered a circular area under each tower with a radius of 100 m from the base of the tower. Where portions of the search area were inaccessible due to sensitive crop species, etc. appropriate adjustments were made in calculations. Bird carcasses were placed in plastic bags, and the following data were recorded: tower identification number, date, closest transect, distance from tower, azimuth to the tower, estimated number of days since death, and observer's name. Once bagged and labeled, carcasses were frozen for later identification and verification of species. I maintained the appropriate USFWS and Michigan Department of Natural Resources (MDNR) permits.

## Observer detection and carcass removal trials

It is unlikely that technicians observe all bird carcasses under communication towers. This is in part due to dense vegetation, observer fatigue, human error, and scavenging by predators. Therefore, each technician's observer detection rate and the rate at which carcasses were removed were quantified at each site (Erickson et al. 2003). Observer detection trials were conducted on technicians at their designated tower once each field season. Technicians were not notified when the observer detection trial would occur, or how many and what species of bird carcasses would be placed at their tower site. By placing 10 bird carcasses within the tower search area, I was able to quantify the proportion of bird carcasses detected by each technician. For observer detection trials I used Brown-headed Cowbirds (*Molothrus ater*) painted to simulate the plumage of migrating songbirds. Bird carcasses used for observer detection trials were also painted with an "invisible" paint that glowed fluorescent colors when viewed under a black light. When analyzing the study data, the "invisible" paint prevented any confusion between birds that had collided with the towers and birds placed in the plots for observer detection trials.

Similarly, technicians placed 15 bird Brown-headed Cowbird carcasses immediately adjacent to the edges of their designated communication tower's search area and recorded the removal (e.g., scavenging) of carcasses daily during the study period. Using these data we calculated a scavenging or removal rate (Erickson et al. 2003). Bird carcasses used in the removal trials were not painted, as this foreign scent may have influenced the removal of carcasses by scavengers. Both observer detection trial birds and removal trial birds were placed in a range of habitats representative of the individual tower search area.

**Statistical analyses**

The Kruskal-Wallis test combined with Tukey's Honestly Significant Difference (HSD) multiple comparison procedures were used to test for differences in avian fatalities among the tower lighting systems from the spring and fall 2008 and 2009 combined (Zar 1998). Using methods developed by W. Erickson (WEST, Inc.), we used the observer detection rate and the carcass removal rate specific for each individual tower to calculate adjustment multipliers by which to correct the observed number of birds per tower. This adjustment method considered the probability that carcasses not found on one day could be found on the following days, depending on the rate of carcass removal (W. Erickson pers. comm.). These two interacting variables were used to determine an average carcass detection probability and the related adjustment multiplier specific to each tower. Both raw data and data adjusted for scavenging and observer detection were used when testing for significant differences among tower types. The statistical software R (2009) was used for Kruskal-Wallis and related multiple comparisons with an $\alpha = 0.10$.

**Results**

Over 20 days in the spring and fall of 2008 and 2009 technicians and I found a total of 162 birds determined to be killed during the study periods (Table 2). During this study the maximum number of birds found in 1 morning at 1 tower was 9 (2 separate days each found 9 birds at the same tower).

Table 2. The numbers of bird carcasses found at 6 Michigan communication towers during 20 days in the spring 2008 and 2009 and 20 days in the fall of 2008 and 2009.

| **Tower light system** | **Number of towers** | **Number of carcasses found** | | | | |
|---|---|---|---|---|---|---|
| | | **Spring 2008** | **Fall 2008** | **Spring 2009** | **Fall 2009** | **Total** |
| White strobe | 3 | 3 (mean = 1.00, SE = 0.58) | 5 (mean = 1.67, SE = 1.67) | 7 (mean = 2.34, SE = 1.45) | 4 (mean = 1.33, SE = 0.67) | 19 (mean = 1.59, SE = 0.53) |
| Red blinking incandescent with non-blinking | 2 | 31 (mean = 15.50, SE = 7.50) | 21 (mean = 10.50, SE = 3.50) | 50 (mean = 25.00, SE = 8.0) | 24 (mean = 12.00, SE = 6.00) | 126 (mean = 15.75, SE = 3.25) |
| Red blinking incandescent without non-blinking | 1 | 3 | 6 | 1 | 7 | 17 (mean = 4.25, SE = 1.4) |
| **Total** | **6** | **37** | **32** | **58** | **35** | **162** |

I identified each specimen to taxonomic species when possible (Table 3). Thirty-eight species of birds were collected and identified to have collided with the towers during the 2008 and 2009 study periods. The Gray Catbird was the most common species observed in the spring 2008 field season, with the Swainson's Thrush the most common species in the fall of 2008 (Table 3). The spring 2009 searches detected more Red-eyed Vireos than other species and the fall 2009 searches found more Blackpoll Warblers than other species (Table 3).

Table 3. Avian fatalities (by species) at 6 Michigan communication towers during 20 days in the spring and fall of 2008 and 2009.

| **Bird Species**[a] | **Numbers of carcasses found** | | | |
|---|---|---|---|---|
| | **Spring 2008** | **Fall 2008** | **Spring 2009** | **Fall 2009** |
| American Pipit (*Anthus rubescens*) | | | 1 (2%) | |
| American Redstart (*Setophaga ruticilla*) | | | 1 (2%) | |
| Baltimore Oriole (*Icterus galbula*) | 1 (3%) | | 1 (2%) | |
| Bay-breasted Warbler (*Dendroica castanea*) | | 1 (3%) | | |
| Black-and-white Warbler (*Mniotilta varia*) | 2 (5%) | | | |
| Blackburnian Warbler (*Dendroica fusca*) | 1 (3%) | | | |
| Blackpoll Warbler (*Dendroica striata*) | | 3 (9%) | 1 (2%) | 6 (17%) |
| Black-throated Blue Warbler (*Dendroica caerulescens*) | 1 (3%) | 1 (3%) | | |
| Black-throated Green Warbler (*Dendroica virens*) | 1 (3%) | | | |
| Blue Jay (*Cyanocitta cristata*) | 1 (3%) | | | 1 (3%) |
| Blue-winged Warbler (*Vermivora pinus*) | | | 1 (2%) | |
| Cape May Warbler (*Dendroica tigrina*) | | | | 2 (6%) |
| Chestnut-sided Warbler (*Dendroica pensylvanica*) | 1 (3%) | | 2 (3%) | |
| Common Yellowthroat (*Geothlypis trichas*) | 4 (11%) | | 4 (7%) | |
| Easter Wood-Pewee (*Contopus virens*) | 1 (3%) | | | |
| Gray Catbird (*Dumetella carolinensis*) | 7 (19%) | 2 (5%) | 5 (9%) | |
| House Wren (*Troglodytes aedon*) | 2 (5%) | | | 1 (3%) |
| Indigo Bunting (*Passerina cyanea*) | 1 (3%) | | 1 (2%) | |
| Magnolia Warbler (*Dendroica magnolia*) | | | | 2 (6%) |
| Mourning Dove (*Zenaida macroura*) | | 3 (9%) | 1 (2%) | 2 (6%) |

| | | | | |
|---|---|---|---|---|
| Nashville Warbler (*Vermivora ruficapilla*) | | 2 (5%) | 1 (2%) | |
| Northern Cardinal (*Cardinalis cardinalis*) | 1 (3%) | | | |
| Ovenbird (*Seiurus aurocapillus*) | 4 (11%) | | 2 (3%) | 1 (3%) |
| Philadelphia Vireo (*Vireo philadelphicus*) | | 1 (3%) | | |
| Pine Warbler (*Dendroica pinus*) | | | | 1 (3%) |
| Red-eyed Vireo (*Vireo olivaceus*) | 2 (5%) | | 9 (16%) | 1 (3%) |
| Rose-breasted Grosbeak (*Pheucticus ludovicianus*) | | | 2 (3%) | |
| Ruby-crowned Kinglet (*Regulus calendula*) | | | 1 (2%) | 1 (3%) |
| Savannah Sparrow (*Passerculus sandwichensis*) | | | | 1 (3%) |
| Song Sparrow (*Melospiza melodia*) | | | | 1 (3%) |
| Sora (*Porzana carolina*) | | | 2 (3%) | |
| Swainson's Thrush (*Catharus ustulatus*) | | 6 (19%) | 2 (3%) | 1 (3%) |
| Tennessee Warbler (*Vermivora peregrina*) | | | 1 (2%) | |
| Wilson's Warbler (*Wilsonia pusilla*) | 2 (5%) | | | |
| Wood Thrush (*Hylocichla mustelina*) | | 1 (3%) | 1 (2%) | |
| Yellow Warbler (*Dendroica petechia*) | 1 (3%) | | 1 (2%) | |
| Yellow-rumped Warbler (*D. coronata*) | 1 (3%) | | | |
| Yellow-throated Vireo (*Vireo flavifrons*) | | | 1 (2%) | |
| Unknown duck[b] | | | 2 (3%) | |
| Unknown -thrush size[b] | | 2 (5%) | 4 (7%) | |
| Unknown –warbler/vireo size[b] | 3 (8%) | 14 (44%) | 10 (17%) | 16 (46%) |
| **Total** | **37** | **32** | **58** | **35** |

[a] all names of birds follow the *AOU Check-list of North American Birds*

[b] bird carcass heavily scavenged preventing identification of species

The mean observer detection rates for the spring and fall 2008 were 0.37 (SD =0.22) and 0.37 (SD =0.21), respectively, and 0.38 (SD =0.33) and 0.25 (SD =0.28) in 2009. The mean carcasses removal rate was 4.4 days (SD = 4.6) and 9.3 days (SD = 7.1) for spring and fall 2008, respectively and was 6.9 days (SD = 45.1) and 19.5 days (SD = 21.6) in 2009. I used the observer detection rate and the carcass removal rate specific to each individual tower to calculate adjustment multipliers by which to correct the observed number of birds. This adjustment method considered the probability that carcasses not found on 1 day could be found on the following days, depending on the rate of carcass removal (W. Erickson pers. comm.). These 2 interacting variables were used to determine an average carcass detection probability specific to each tower ranging between 1.5 and 20.0 (mean = 7.9, SD = 6.4) for the spring 2008 and 1.1 and 10.0 (mean = 3.9, SD = 3.2) for the fall 2008. The average carcass detection probability specific to each tower ranged between 1.1 and 7.0 (mean = 3.3, SD = 2.2) for the spring 2009 and 1.1 and 16.9 (mean = 7.6, SD = 7.3) for the fall 2009.

Before adjusting for carcass removal and observer detection rates, Kruskal-Wallis ANOVA for ranks found significant differences in avian fatalities among towers with different lighting systems ($\chi^2_2 = 16.51$, P = 0.0003; 2008 and 2009 data combined). Similarly, when all towers were included in the analysis but adjustments made for carcass removal and observer detection rates significant differences were found among the tower lighting types ($\chi^2_2 = 16.49$, $P \leq 0.0003$). Tukey's multiple comparisons found that towers with non-blinking lights were involved in significantly more avian fatalities than towers with only white blinking lights ($P \leq 0.05$) or only red blinking lights ($P \leq 0.05$). There was no significant difference in the numbers of avian fatalities between towers lit with red blinking lights and towers lit with white blinking lights.

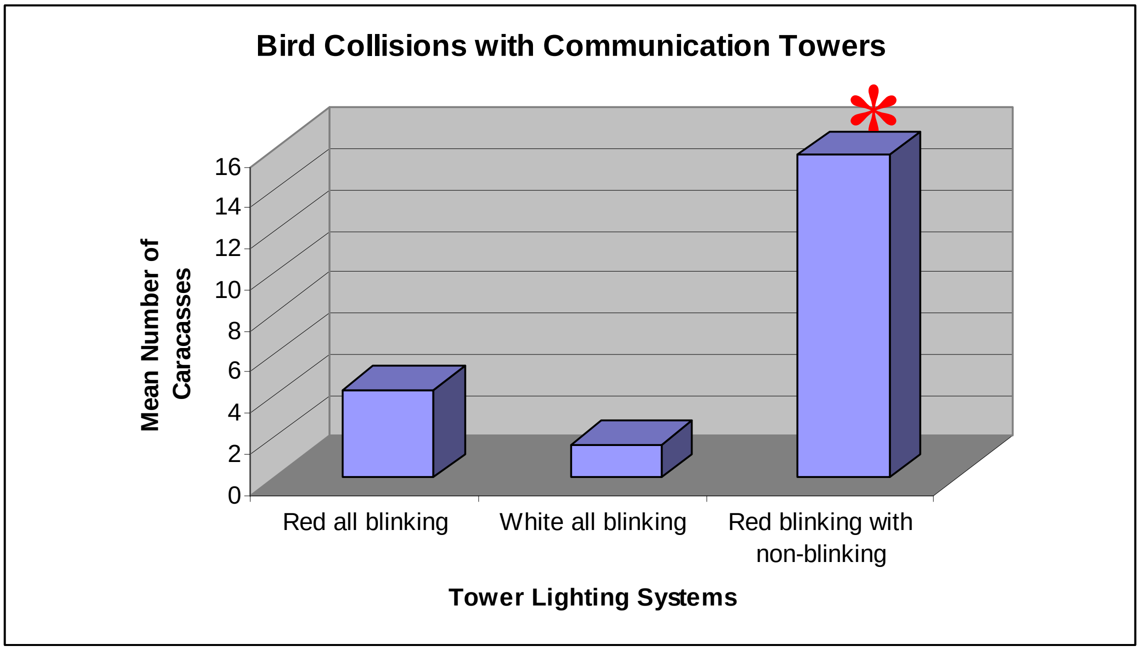



Figure 8. Bird carcass count data (raw) were compared at 6 Michigan communication towers > 277 m Above Ground Level (AGL), during the spring and fall of 2008 and 2009. Three different lighting systems were used on the towers. A sample of the areas under towers were systematically searched for bird carcasses during 20 consecutive mornings surrounding the peak of songbird migration.

**Discussion and objectives for the tall Michigan tower study in 2008 and 2009**

These results suggest that avian fatalities at communication towers can be significantly reduced by using white strobe lights or blinking red lights instead of the more common lighting system of red blinking lights combined with non-blinking red lights (Fig. 6). Similar to previous research on the effects of lighting systems on avian collisions, which was conducted at 116-146-m AGL towers, fatalities were more than 70% less frequent at > 277 m AGL towers lacking non-blinking, red lights (Gehring et al. 2007). These results are also supported by research conducted by Gauthreaux and Belser (2006) who used radar ornithology to observe night-migrating songbirds' flight behavior responses when encountering tall communication towers lit at night with either white strobe lights or red blinking lights combined with red non-blinking lights. They found that when birds were near the red, non-blinking lights that they deviated from a straight, direct azimuth of migration and instead flew in a more circular pattern toward the tower; whereas birds flying near a tower with only white strobe lights did not deviate as commonly. In the spring of 2009, our study included two towers > 277 m AGL that were

1.25 miles away from each another. One tower had a status quo red lighting system with non-blinking lights combined with blinking lights, while the other tower had only white strobe lights. Both tower search areas were in bare dirt and agricultural crops and the same technician searched both towers alternating which tower he started at each morning (Fig. 9). Over the 20-day sample period the tower with the red lighting system was involved in 33 avian fatalities but the nearby tower with white strobe lights was only involved in 2 avian fatalities. This is a specific example supporting the suggestion that birds moving through an area during migration are more attracted to the non-blinking lights of red lit towers than they are to blinking white lights.

Extinguishing non-blinking, red lights would not only benefit avian conservation but would also be financially and logistically beneficial to tower owners, as it would reduce maintenance and utility costs. However, tower owners and operators are required by the Federal Communications Commission (FCC) to follow the recommendations of the FAA. Currently, the FAA allows only the white strobe system to be used at night without non-blinking lights (FAA 2000). Although white strobe systems provide an FAA approved option to significantly reduce avian collisions, the general public generally finds them aesthetically disturbing compared to red blinking lights. In addition, converting communication towers with traditional lighting systems to white strobe systems can be prohibitively costly for tower companies. Fortunately, the FAA is currently exploring the possibility of changing their recommendations to allow the non-blinking, red lights to be extinguished on towers lit with standard red light systems. Given their mandate for air safety, the FAA will need to conduct proper tests of tower visibility or conspicuity to pilots before such recommendations are changed in order to allow this cost efficient and effective option for tower companies.

This study provides a highly unique opportunity to detect consistent differences in bird fatalities among tower light systems.

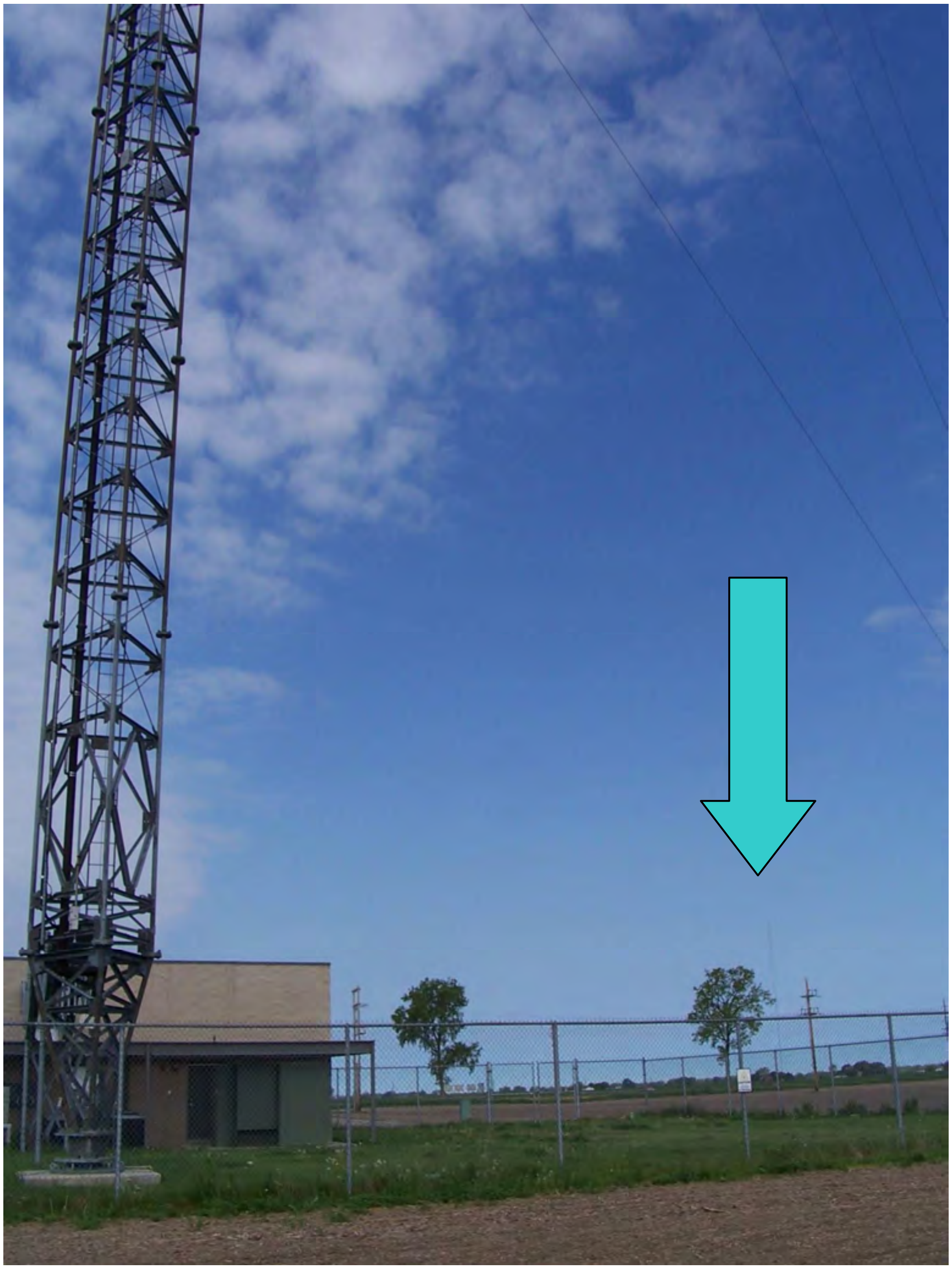


Figure 9. Communication tower lighting systems were compared at 2 Michigan towers > 277 m Above Ground Level that were separated by 1.25 miles. The areas under these towers were simultaneously and systematically searched for bird carcasses during 20 consecutive mornings surrounding the peak of songbird migration in the spring 2009 to compare the relationships between avian fatalities and tower lighting systems. The tower delineated by the blue arrow was lit with white strobe lights and was involved in 2 avian fatalities, while the more proximate tower was lit with non-blinking and blinking red lights and was involved in 33 avian fatalities.

**Acknowledgments**

This study could not be completed without the dedication, enthusiasm, and hard work of the technicians who conducted the early morning searches under communication towers -regardless of rainy and cold conditions. The USCG is commended and thanked for granting access to their Rescue 21 tower and for making this important and unique study possible with their funding and support. This study is made possible by the inclusion of towers greater than > 277 m AGL. I owe a large amount of thanks to the private tower owners and engineers who, by allowing us access to their sites, are taking important steps towards learning more about the issue of bird collisions with communication towers and cost-effective methods to reduce the collisions. W. Erickson (WEST, Inc.) generously provided assistance and formats for calculating average detection probabilities considering both removal and observer detection rates. The interpretation and applicability of this study is greatly enhanced by his shared expertise. C. Mensing (USFWS) and his technicians generously provided Brown-headed Cowbird carcasses. Many individuals provided ideas, suggestions, and support for this project and similar previous projects, including but not limited to: A. Manville (USFWS), T. Tansey (USCG), C. Hajduk (USCG), C. Czarnecki (USFWS), S. Lewis (USFWS), P. Kerlinger (Curry & Kerlinger, LLC). Several agencies and organizations provided support and collaboration: Michigan Department of Natural Resources (MDNR), New Jersey Department of Environmental Protection- Division of Fish and Wildlife, Federal Aviation Administration, FCC. I am particularly grateful for the foresight of C. Schumacher (USFS) who initially collaborated with the FAA and a tower owner requesting that one of the current study towers be altered to only blink (without non-blinking lights). This unique tower lighting system holds promise for significantly reducing avian collisions if the FAA deems it safe for aviators. I would like to express my gratitude to the USCG, USFWS, and the National Fish and Wildlife Foundation (NFWF) for granting funds to improve this project. The views and conclusions contained in this document are those of the author and should not be interpreted as representing the opinions or policies of the U.S. Government or the National Fish and Wildlife Foundation. Mention of trade names or commercial products does not constitute their endorsement by the U.S. Government or the National Fish and Wildlife Foundation. Michigan Natural Features Inventory, Michigan State University, and Central Michigan University provided greatly appreciated logistical support for this research. My colleagues at the Michigan Natural Features Inventory provide both logistical and technical support; especially H. Enander, B. Klatt, Y. Lee, S. Ridge, and N. Toben.

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APPENDIX B—FEDERAL AVIATION ADMINISTRATION OBSTRUCTION LIGHTING STYLES

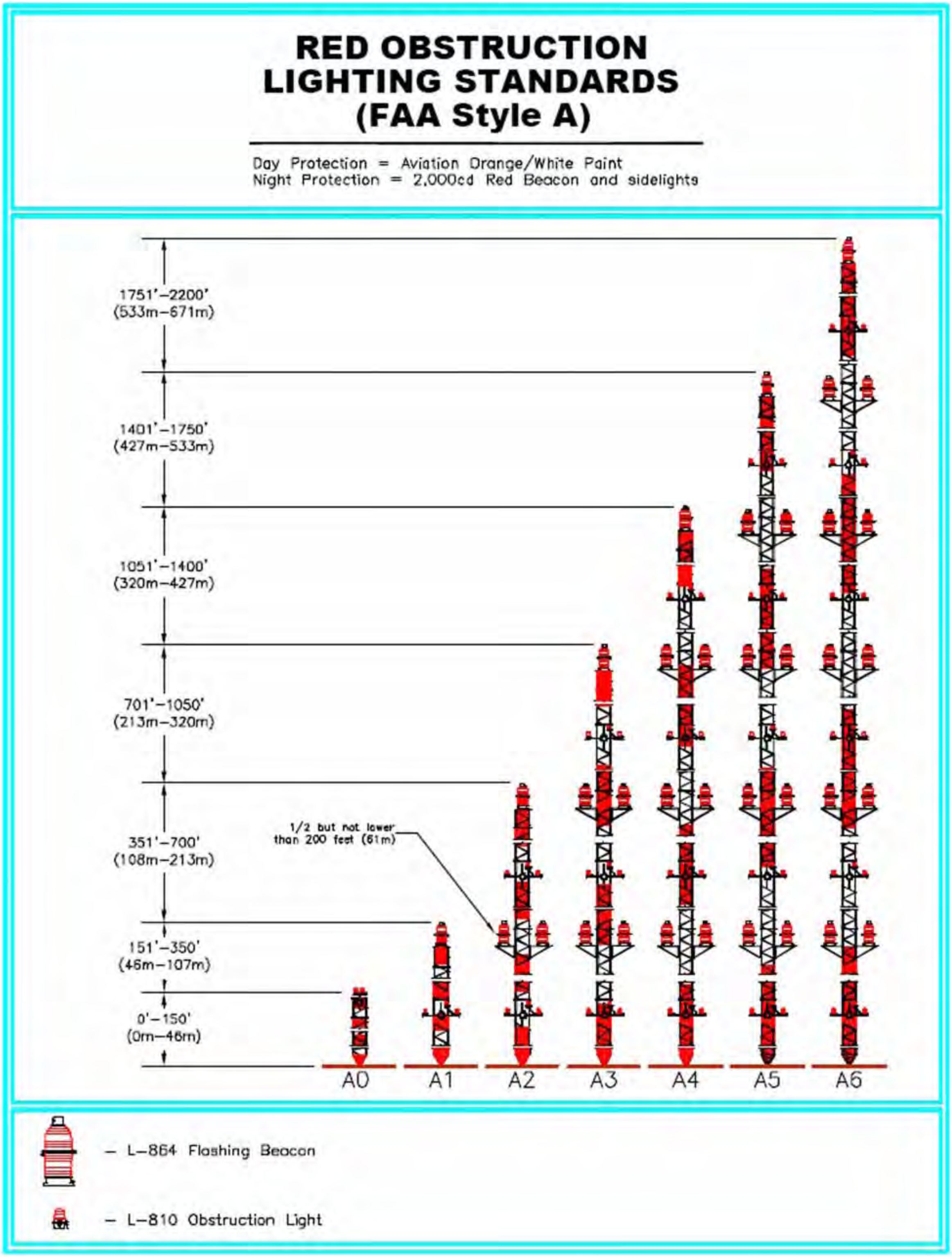



Figure B-1. The Federal Aviation Administration Style A Lighting Configuration

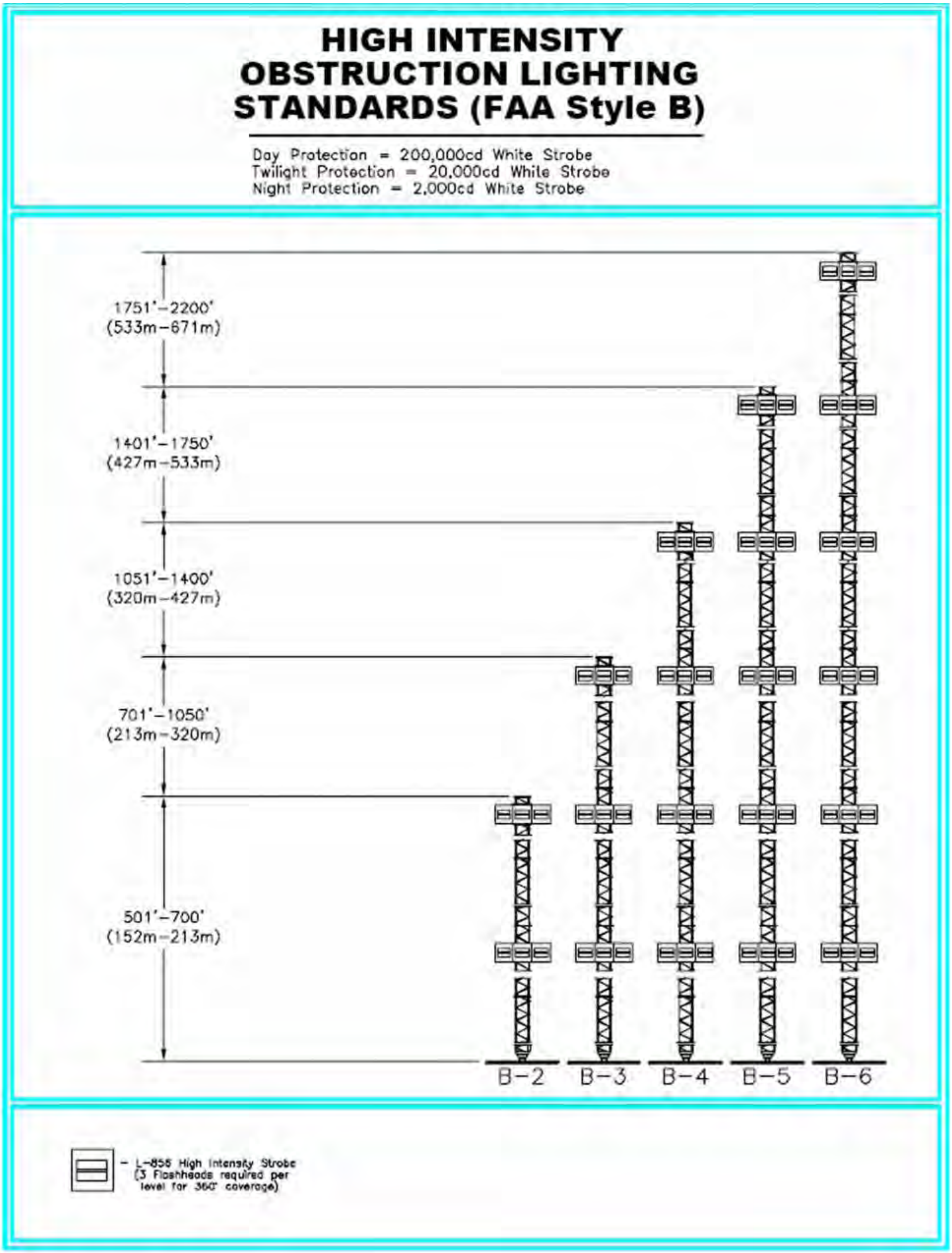
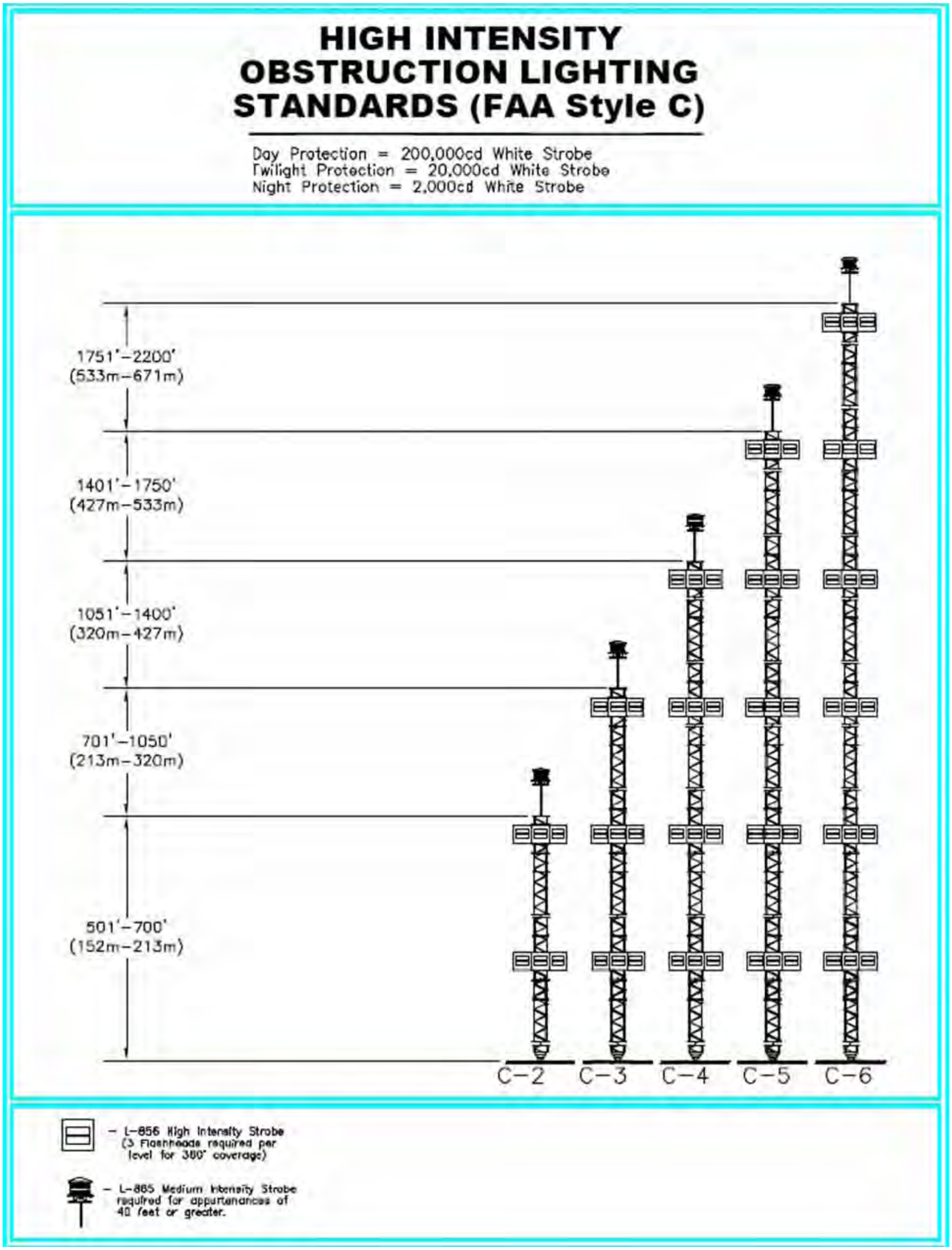



Figure B-2. The Federal Aviation Administration Style B Lighting Configuration

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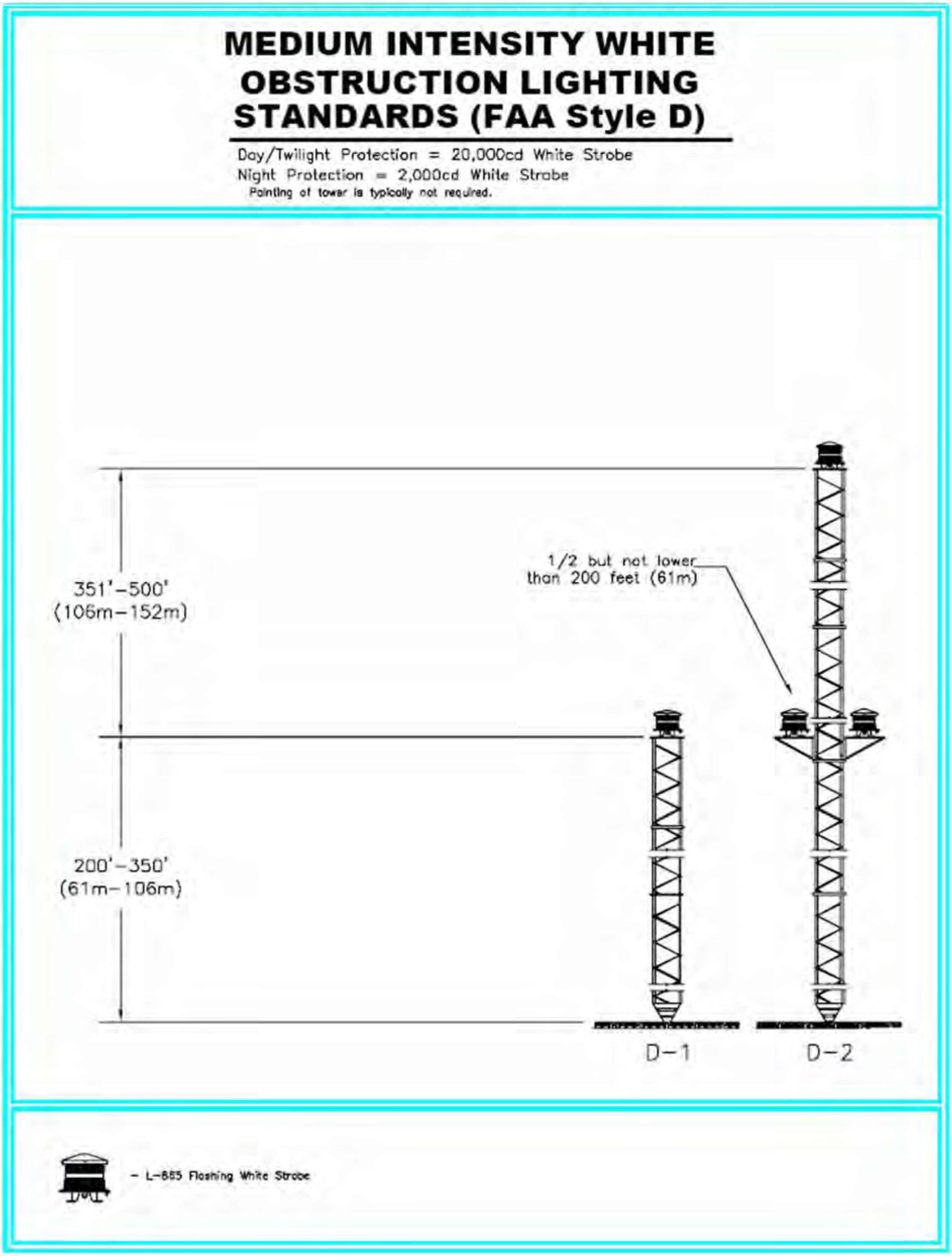


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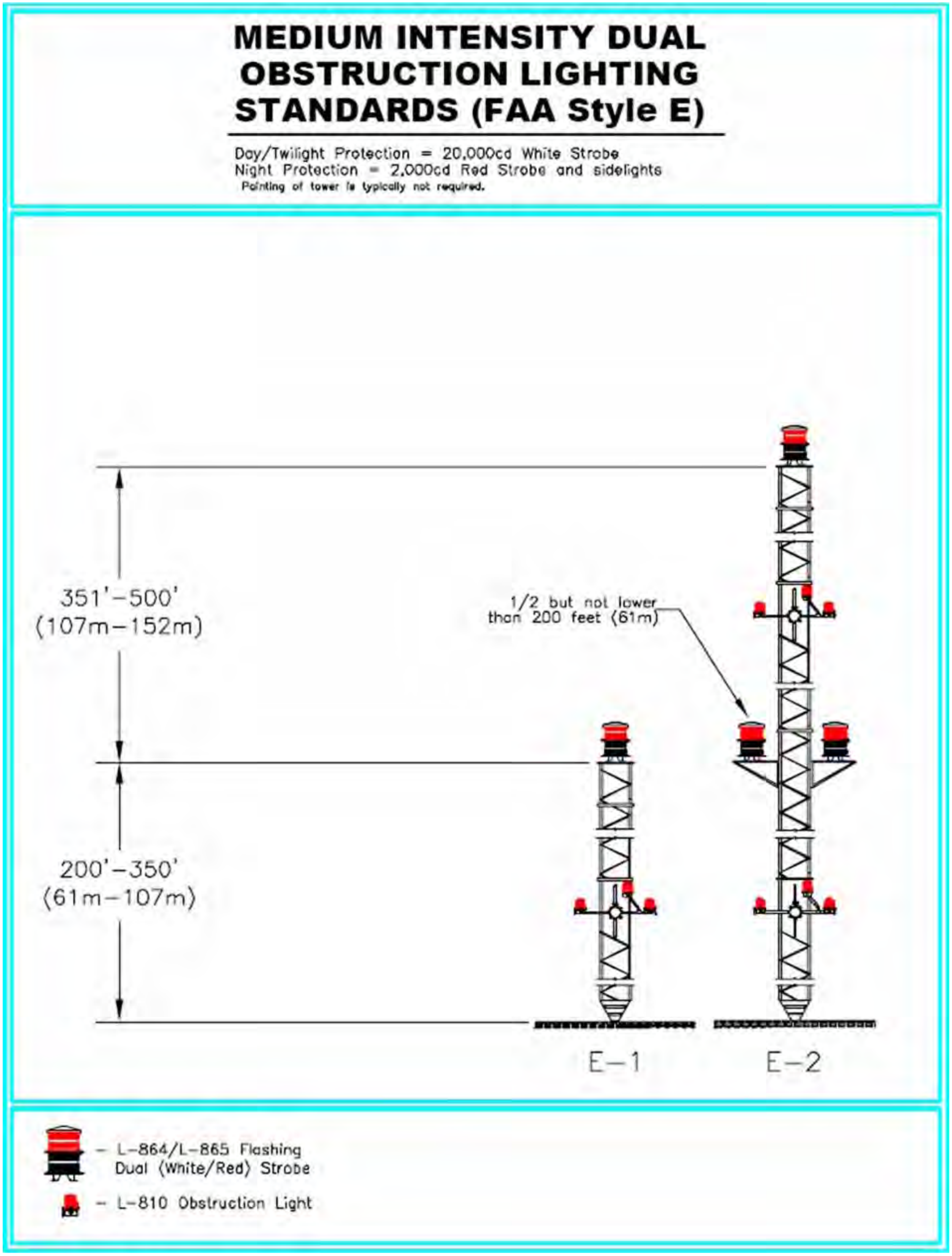


Figure B-5. The Federal Aviation Administration Style E Lighting Configuration

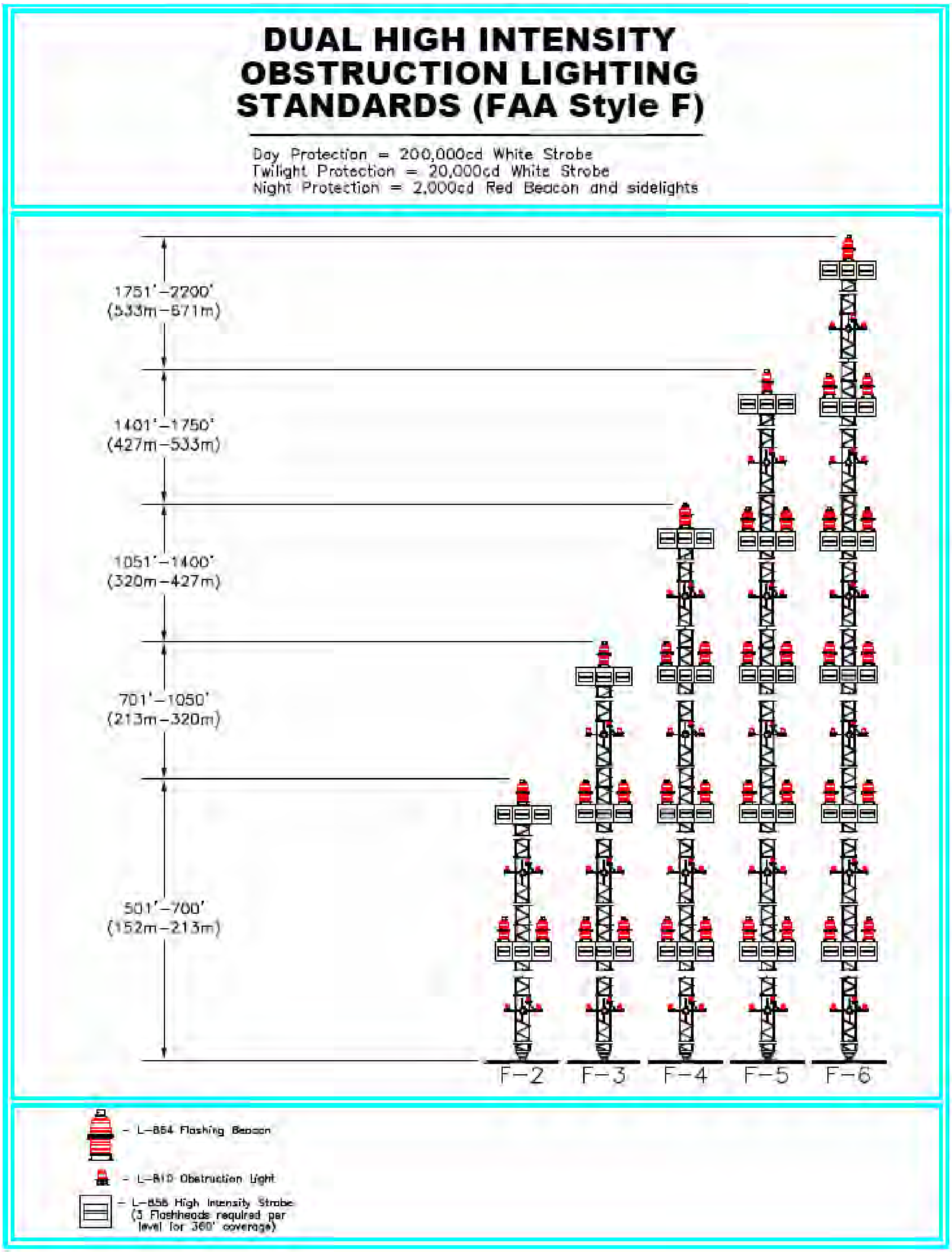


Figure B-6. The Federal Aviation Administration Style F Lighting Configuration

APPENDIX C—PROPOSED FEDERAL AVIATION ADMINISTRATION OBSTRUCTION LIGHTING STYLES

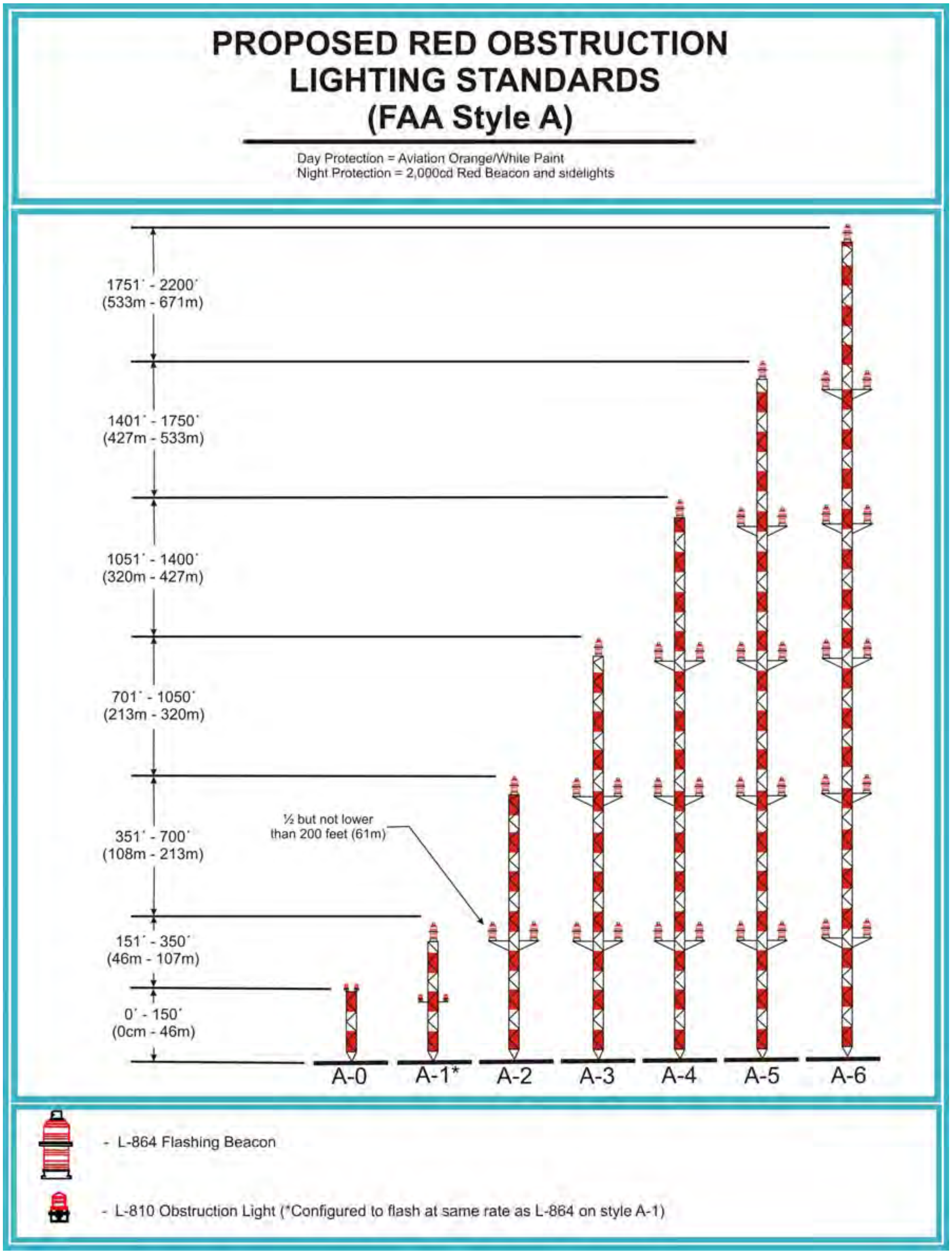


Figure C-1. Proposed Federal Aviation Administration Style A Lighting Configuration

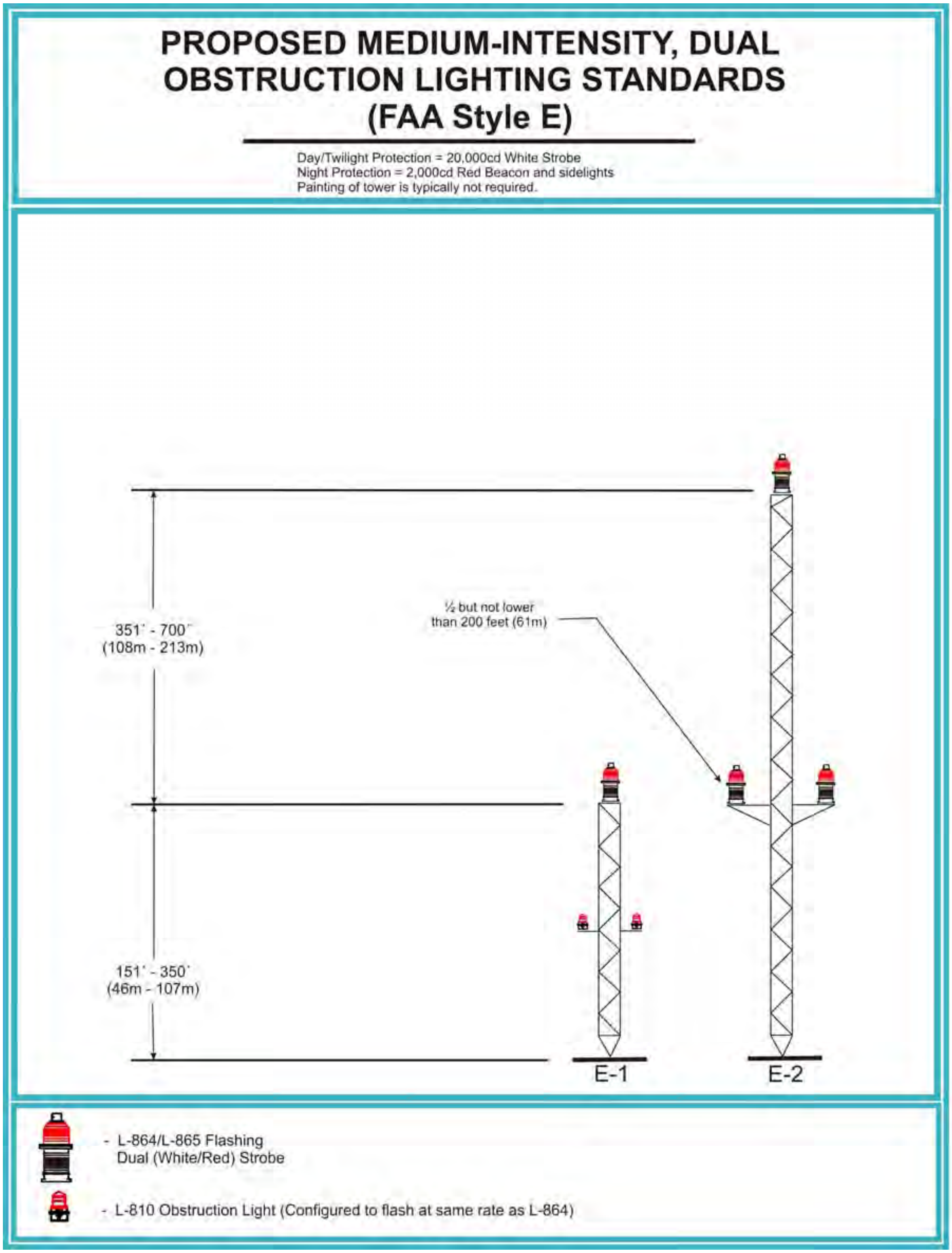


Figure C-2. Proposed Federal Aviation Administration Style E Lighting Configuration

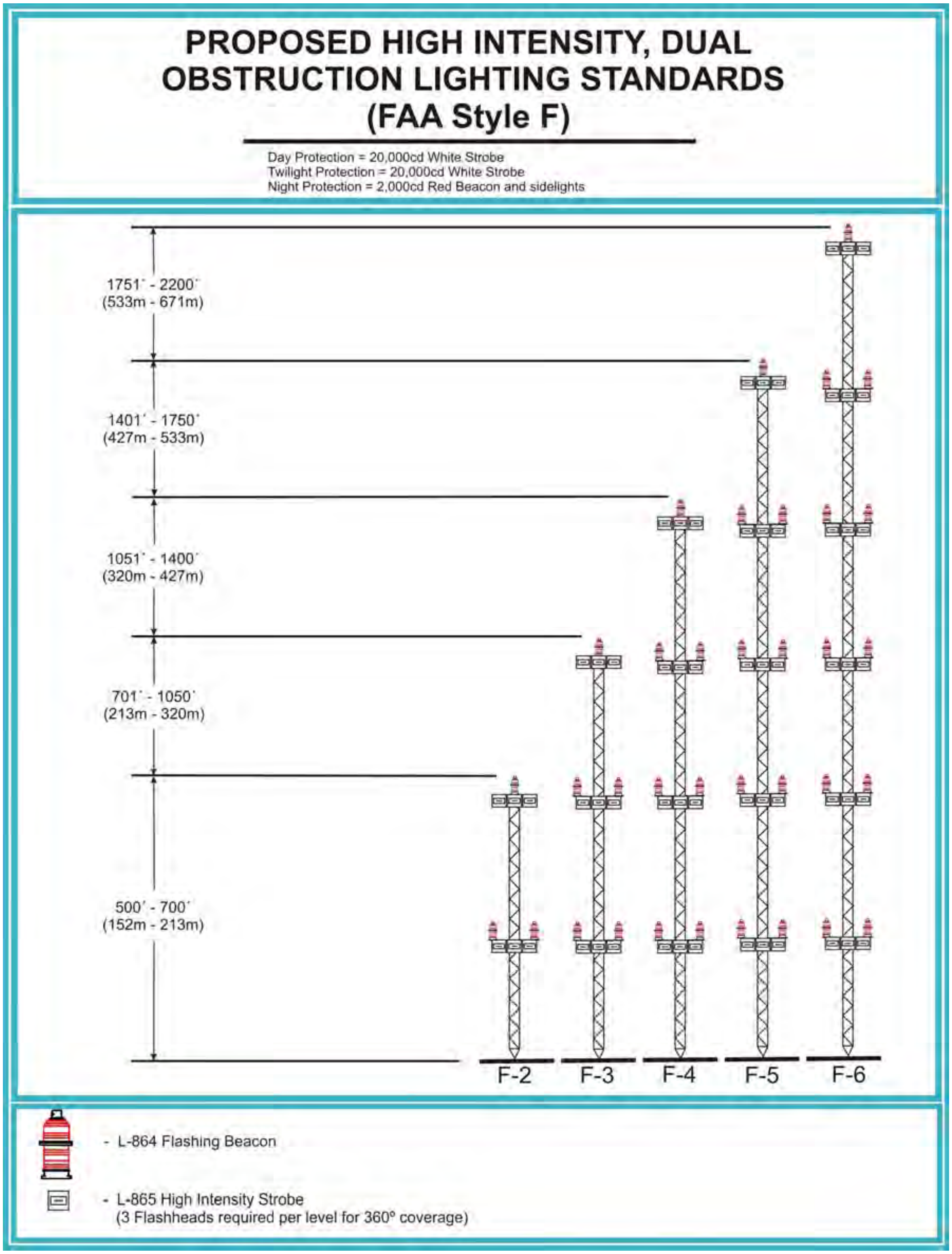


Figure C-3. Proposed Federal Aviation Administration Style F Lighting Configuration