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Researchers Develop New Power-line Marker To Help Avoid Wire Strikes in Low Light

Wire strikes continue to be one of the most significant hazards to helicopter operations. A solar-powered, highly reflective marker makes all wire types easier to identify at night.

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The helicopter pilot was flying a contract mission for the Arizona (U.S.) Department of Fish and Game, transporting department personnel on a wildlife-population survey. A mission requirement was to fly at 200 feet (61 meters) or less above ground level (AGL). After flying the Bell 206B for 1.5 hours without incident, the pilot was told to reposition the helicopter for surveying a different area.

En route, during cruise at an altitude of 180 feet (55 meters) AGL, the helicopter collided with a power line, entered an uncontrolled descent and struck the ground. A postimpact fire destroyed the helicopter. One fatal injury and three serious injuries resulted from the Jan. 4, 1994, accident. Although the power line was shown on the sectional chart, there were no markers on the power line, which was reported by other pilots to be extremely difficult to see.

Wire strikes are among the most significant threats to both military and civil helicopter operations. The U.S. Army Safety Center at Fort Rucker, Alabama, reported 97 U.S. military helicopter wire strikes between 1990 and 1996, resulting in 14 fatalities and total losses of US$64 million.

Statistics from the U.S. National Transportation Safety Board (NTSB) show 87 U.S. civil helicopter wire-strike accidents between 1990 and 1995, which resulted in 29 fatalities. An additional eight wire-strike accidents were listed through the third quarter of 1996 (Figure 1, page 2). Wire-strike accidents fluctuated yearly, accounting for between 6.17 percent and 10.47 percent of civil helicopter accidents between 1990 and 1995.

Sixty-seven percent of the military wire-strike helicopter accidents occurred during daytime hours; the greater total of helicopter flight hours occurred during daylight. Most of the wire-strike accidents involved known wire hazards that were shown on aeronautical charts. But daytime wire strikes, although the most numerous, are usually the least severe, with more than two-thirds of the accidents causing less than US$2,000 damage to the aircraft and involving no fatalities.

Nighttime wire strikes tended to be more severe and much more costly. About 72 percent of the total U.S. military losses caused by wire strikes were incurred at night, with a much larger percentage of fatalities or serious injury. Five times as many such accidents occurred at night; of the 14 fatalities from wire strikes, seven (50 percent) involved nighttime operations.

No one is certain why nighttime wire strikes tended to be more severe, but one theory is that nighttime strikes often involve larger wires that would be more likely to be seen and avoided in the daytime, and that have the potential for greater rotor damage.

Contributing to these statistics are growing numbers of nap-of-the-earth flights (flying as close to the ground as possible) by military helicopters, which place the aircraft close to power lines, telephone cables and structural support cables. Flight conditions are often far from ideal — flying through inclement weather, rather than around it, and in near-darkness.

Because of the risk inherent in low-level flight, pilot-training programs have increasingly emphasized hazard avoidance and crew vigilance. Pilots are taught to mark known hazards on their flight maps.

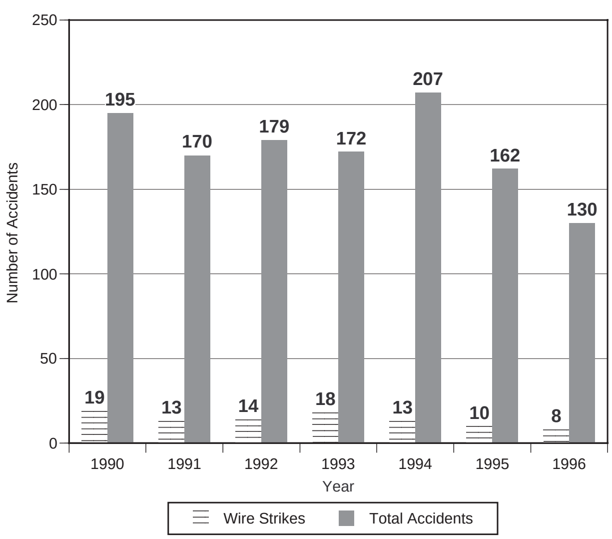
Nevertheless, wire strikes continue to occur. Pilots become distracted or make poor decisions; visual meteorological conditions (VMC) can deteriorate quickly; and wire markers might be difficult to recognize, particularly under low-light conditions.[1]

Since wire markers were introduced more than a decade ago, designs have been modified to make markers more visible. Initially, simple international-orange spheres were hung on wires to mark them, especially in high-traffic areas (photo, upper right).

These 29.2-centimeter (11.5-inch)-diameter spheres, made of fiberglass, were passive. They contained no moving parts or wiring and required no maintenance after installation. Although the bright orange color faded over time, passive markers proved to be a relatively inexpensive first effort to mark wire hazards.

Another type of wire marker, which was developed for use on power lines, is spherical and glows as the result of the electrical

U.S. Civilian Helicopter Accidents, 1990–1996



Note: 1996 data through third quarter.

Source: Helicopter Association International/ U.S. National Transportation Safety Board

Figure 1

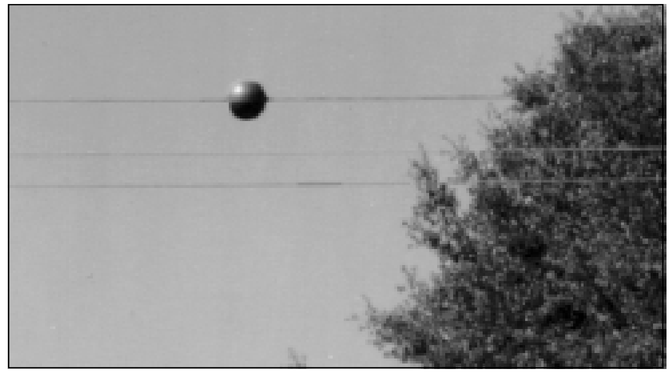


Photo: U.S. Army Aeromedical Research Laboratory

International-orange spheres were early-generation wire markers.

field of the power line. The sphere requires no other power source and no maintenance.[2]

In an attempt to increase the visibility and conspicuity of wire markers by researchers, 2.5-centimeter (one-inch)-wide highly reflective tape in a cross pattern has been applied to the markers. Pilots' ability to recognize these markers varied greatly with changing backgrounds, time of day, weather, sun angle and the viewing means (naked eye, thermal sensor or image intensifier).

Research is also under way at the U.S. Army Aeromedical Research Laboratory (USAARL) at Fort Rucker, Alabama. A proposed alternative marking-system design was submitted to the U.S. Army in 1991. The design was a molded international-orange polyhedron with circular, 5.1-centimeter (two-inch)-diameter patterns of 3M Scotchlite™ reflective sheets applied to the individual faces of the polyhedron. [The polyhedron design allowed for various numbers of faces, with 24 a typical number.] This reflective material, similar to that used on automobile highway traffic-control signs, consisted of prismatic lenses formed in a transparent synthetic resin, sealed and backed with a pressure-sensitive adhesive. Using the principle of retroreflection [reflection of light in such a way that the paths of the reflected rays are parallel to those of the incident rays], this sheeting significantly increased the conspicuity of the marker.

To determine the effectiveness of the proposed design, USAARL conducted a study to compare its performance with current wire markers. Initial testing involved five international-orange wire-marker designs (Figure 2, page 3):

- Design 1: a uniform sphere;
- Design 2: a uniform sphere with white reflective tape in an "X" pattern;
- Design 3: a uniform, nonreflective polyhedron;
- Design 4: a uniform polyhedron with circular patterns of white retroreflective sheeting; and,
- Design 5: a uniform polyhedron with circular patterns of yellow retroreflective sheeting.

Wire-marker Designs Tested by U.S. Army Aeromedical Research Laboratory

Source: U.S. Army Aeromedical Research Laboratory

Figure 2

Testing was conducted in daytime and nighttime conditions and involved 16 volunteers, who were waiting to begin helicopter flight training at Fort Rucker. All had passed the U.S. Army Class I flight physical examination requiring at least 20/20 (6/6) or better uncorrected vision and normal color vision. Four of the subjects had served as aeroscout observers and had previous experience with night-vision goggles. The remaining subjects had no previous helicopter flight time or night-vision goggle experience.

The first testing phase was conducted in clear, sunny daytime conditions, including both early-morning and overhead sun angles. In the second phase, nighttime trials were conducted under clear conditions with more than 23 percent of the moon's visible surface illuminated. In both phases, the various designs of wire markers were placed at the end of the stagefield, mounted on three-meter (10-foot) posts. The posts were placed in a row in front of a tree line. The positions of the wire markers along the row were changed randomly throughout the test.

All subjects viewed the markers from either the left- or the right-rear seat of a low-hovering Bell UH-1 helicopter, with the observers looking downfield through the open cargo doors. During the two-day test period, all daytime trials began at the maximum viewing distance of 1,281 meters (4,200 feet), the length of the staging field. The helicopter hovered at about 4.6 meters to 6.1 meters (15 feet to 20 feet) AGL, just above the altitude where rotor wash would produce a ground effect. All the markers were found to be equally visible in the daytime, whether viewed with the naked eye or through a tinted visor. This "ceiling effect," in which no distinction in marker visibility was found even at the maximum viewing distance, was present for nearly all subjects, wearing either clear or tinted visors.

Nighttime trials were conducted differently because of the reduced ranges associated with low-light viewing. A descending method of limits was used and observation began where the marker was known to be visible (30.5 meters [100 feet]) and then repeated as the helicopter moved away from the markers in 30.5-meter intervals. [A descending method of limits is a standard experimental/statistical method. For example, in this study the aircraft moved away from the marker in 30.5-meter increments. If the subject could not see the marker in two consecutive increments the lower value was used.]

Under standard helicopter-lighting configurations (position lights alone or anticollision lights in combination with position lights), the reflective polyhedron designs provided the greatest detection ranges. Marker design 2, with the reflective "X" pattern, although superior to both design 1 (the blank sphere) and design 3 (the nonreflective polyhedron), provided only 20 percent to 44 percent of the detection range of marker designs 4 and 5 (the polyhedrons with retroreflective sheeting).

But, as in the daytime trials, ceiling effects precluded detection of the differences among any of the reflective designs. Under blackout conditions, where the sources of illumination were limited to the moon and ambient artificial lighting, detection ranges were reduced markedly (and were nearly equivalent) for each design.[3]

Efforts to improve the polyhedral marker culminated in a new design (U.S. patent no. 5,537,111) that enhances both nighttime and daytime conspicuity. The original polyhedral design was modified to operate in two distinct modes, a passive daytime mode and a luminous nighttime/inclement-weather mode using light-emitting diodes (LEDs). These two modes are intended to facilitate both naked-eye and electro-optical image intensification detection.

The five distinct components of the new design are power supply, power-supply voltage monitor, light-level detector, logic control and visibility-enhancement module (Figure 3, page 4). The visibility-enhancement module in the daytime mode, consists of surface-mounted circular retroreflectors. In the nighttime mode, it consists of flashing LEDs located at the center of the retroreflectors. The logic control activates the LEDs when the light-level detector indicates that the

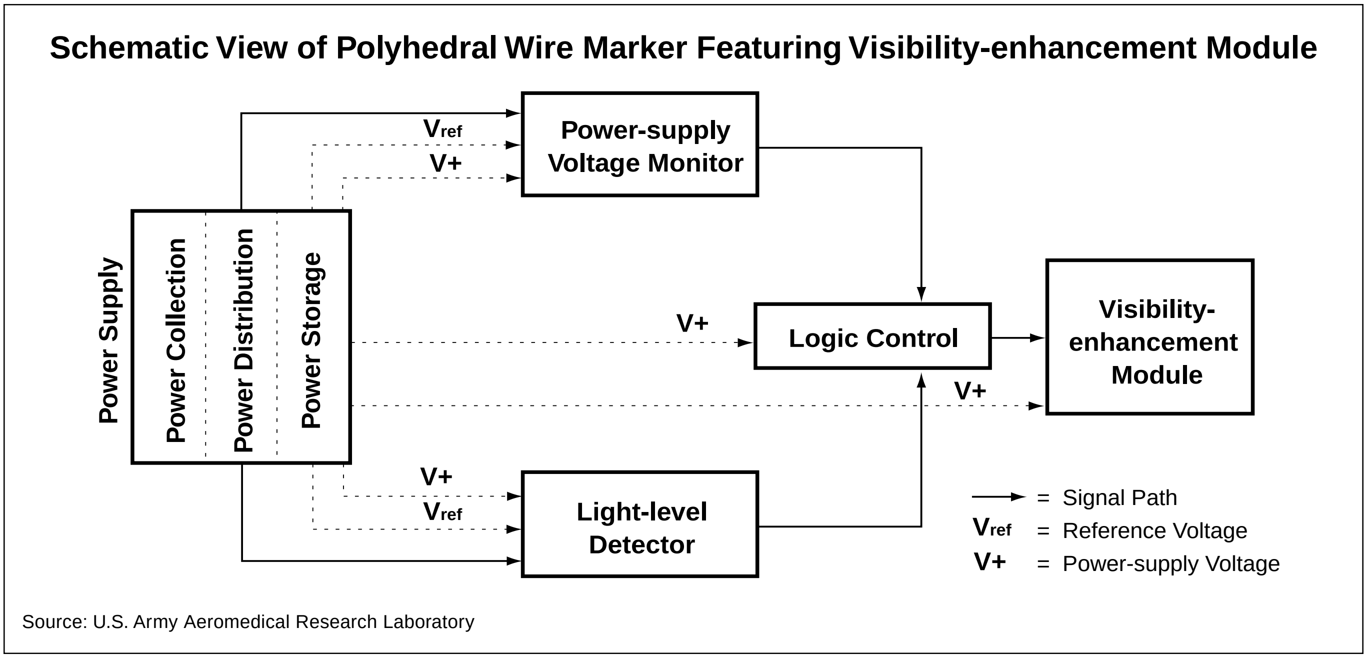


Figure 3

ambient illumination has fallen below a preselected threshold, and the power-supply voltage monitor indicates that the battery voltage is adequate. The power supply consists of one or more solar cells that recharge a nickel-cadmium (nicad) battery pack. Figure 4 shows both external and internal views of this new design.

During limited field and bench tests, a fully integrated wire-marker module was tested under daytime, nighttime and inclement-weather conditions. During the daytime, the solar cells provided adequate voltage to charge the nicad batteries in the battery pack. The transition from daytime to nighttime mode was instantaneous when the ambient light fell below the prescribed level. Testing included a period of inclement weather during which the unit operated continuously for 75 hours in the nighttime/flashing mode.

In a second field detection test, the patented design was evaluated under the previously discussed daytime/nighttime unaided/aided conditions. As shown in Table 1 (page 5), the mean detection distance for the LED-equipped marker was 1,281 meters (the ceiling for the range test), equaling or exceeding the values for all other test designs for every test condition. In addition, anecdotal data from USAARL aviators indicated that it was

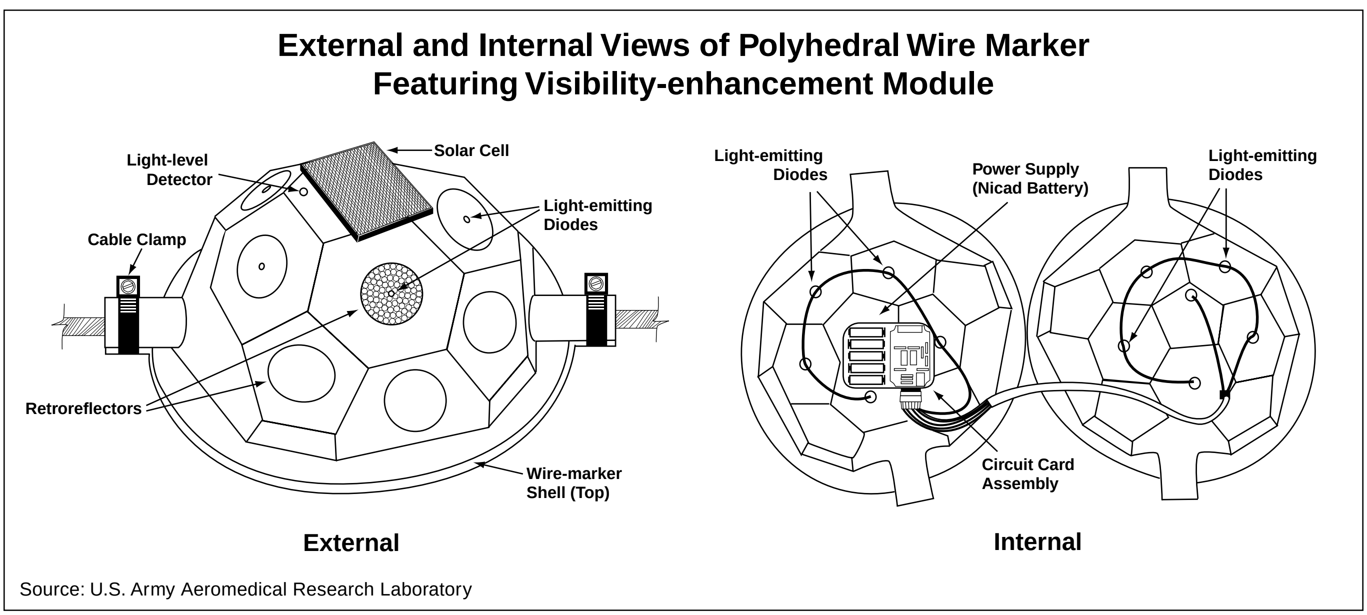


Figure 4

Table 1
Detection Distances for Various Wire Marker Designs, Meters (Feet)

	Design 1		Design 2		Designs 4 and 5		Light-emitting Diode Design	
Day, Unaided Eye	1,281	(4,200)	1,281	(4,200)	1,281	(4,200)	1,281	(4,200)
Night, Unaided Eye								
Position lights	38	(125)	149	(488)	1,281	(4,200)	1,281	(4,200)
Anticollision lights	65	(213)	210	(688)	374	(1,225)	1,281	(4,200)
Searchlight	366	(1,200)	1,281	(4,200)		(4,200)	1,281	(4,200)
Blackout	19	(63)	38	(125)	42	(138)	1,281	(4,200)
Night, Second-generation Image Intensifier								
Position lights	137	(450)	381	(1,250)	602	(1,975)	1,281	(4,200)
Infrared searchlight	160	(525)	419	(1,375)		(1,975)	1,281	(4,200)
Blackout	229	(750)	252	(825)	259	(650)	1,281	(4,200)
Night, Third-generation Image Intensifier								
Position lights	145	(475)	435	(1,425)	625	(2,050)	1,281	(4,200)
Infrared searchlight	175	(575)	488	(1,600)	686	(2,250)	1,281	(4,200)
Blackout	229	(750)	252	(825)	290	(950)	1,281	(4,200)

Note: Maximum available range was 1,281 meters (4,200 feet).
Viewing conducted from helicopter hovering 4.6 meters to 6.1 meters (15 feet to 20 feet) above ground level.

Source: U.S. Army Aeromedical Research Laboratory

possible to see the LED-equipped marker design from a distance of 305 meters (1,000 feet) while at an altitude of 200 feet (61 meters) and approaching at a speed of 70 knots (130 kilometers per hour). These promising results were recorded under high-temperature, high-humidity conditions, with scattered cloud cover at 4,000 feet (1,213 meters).[4]

Enhanced visibility during both daytime and nighttime is the predominant advantage of this self-powered wire-marker design. Its ability to recharge itself automatically and switch modes as lighting conditions change makes it a versatile and low-maintenance alternative to current passive designs. When placed on any type of wire — power line, telephone cable or structural support cable — this marker provides additional safety for both daytime and nighttime helicopter flights. Researchers at USAARL, Fort Rucker, continue to field test and evaluate the design under a variety of weather conditions.♦

References

1. Leister, G.A. “Wires — The Indiscriminate Killer!” *Helicopter Safety* Volume 15 (September–October 1989).

2. Richard Milton, developer of this power-line marker, in 1993 received the Adm. Luis de Florez Flight Safety Award, presented by Flight Safety Foundation for this achievement.

3. Levine, R.R.; Rash, C.E.; Martin, J.S. *Conspicuity Comparison of Current and Proposed U.S. Army Wire Marker Designs*. U.S. Army Aeromedical Research Laboratory. Report no. 91-9. 1991.

4. Snook, E.H.; Rash, C.E.; et al. *Solar-Powered Light Emitting Diode Power Line Avoidance Marker Design.* U.S. Army Aeromedical Research Laboratory. Report no. 93-6. 1993.

Further Reading from FSF Publications

“Descent Below Normal Surveillance Altitude Ends in Fatal Wire Strike.” *Helicopter Safety* Volume 23 (January–February 1997).

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