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**Flight Helmets: How They Work
and Why You Should Wear One
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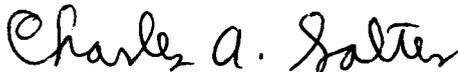
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Flight Helmets: How They Work and Why You Should Wear One

■ John S. Crowley, MD, MPH; Joseph R. Licina, MSS; James E. Bruckart, MD, MPH

Introduction

THE MOST COMMON CAUSE OF DEATH IN aircraft accidents of all types is head injury.¹⁻³ Over the years, several strategies have been employed to reduce the incidence of head injury. These include the use of lap belt and shoulder harness restraint systems, and making the cockpit less lethal by eliminating sharp knobs and other protrusions, increasing the amount of space around the occupant, and padding surfaces likely to cause injury.^{4,5} This paper reviews another classic but surprisingly controversial approach—the flight helmet.

Helmet History

Protective helmets have been around as long as armed conflict. Originally, their main purpose was to protect the head from blows from primitive weapons; later, helmets helped stop crossbow bolts and musket balls. These early helmets didn't permit much mobility of the head and neck—one medieval armor helmet worn by Charles V weighed over 40 lb.⁶

In 1908, while flying with Orville Wright, an unhelmeted Army pilot

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Figure 1. World War I experimental helmet, circa 1918. (Reprinted from Dean B: *Helmets and Body Armor in Modern Warfare*. 2nd ed, Tuckahoe, N.Y., Carl J. Pugliese, 1977.)

named Thomas Selfridge became the first powered airplane fatality when he suffered lethal head injuries in the crash of a Wright Flyer.⁷ Subsequently, a few American aviators, including Lt. Henry "Hap" Arnold (later General Arnold), began wearing leather football helmets to protect the skull from injury in case of a crash.⁸ In Great Britain, many early aviators wore modified hard motorcycle racing helmets to avoid injury.⁹



Figure 2. The APH-5 Helmet (official U.S. Army photograph).

During World War I, allied instructors and students continued to wear these rigid-style helmets, while most operational pilots opted for soft leather flying helmets that afforded better head movement and some protection from wind and cold, but precious little crash protection. Late in the war, it was recognized that aviators needed more ballistic protection, and a 2 lb steel flight helmet was designed (Figure 1).⁶

Flight helmets for bomber crews in World War II were similarly intended for ballistic protection (primarily from flak), and many lives



Figure 3. The SPH-4 Helmet (official U.S. Army photograph).

were saved by these steel-plated helmets.⁶ Toward the end of World War II, helmets were also designed for impact protection, mainly for use in new jet aircraft. Test pilots were encountering severe buffeting when flying at high speeds in turbulence, incurring head injuries from contact with the aircraft canopy.⁸ Protecting the head during an ejection sequence also was a growing concern.

Thus, a philosophy of head protection for fixed-wing aviators evolved (and endures to this day) that relied on in-flight escape to protect the fixed-wing aviator from crash forces. For the rotary-wing pilot, who must "ride out" the entire crash sequence inside the aircraft, head protection requirements are much more demanding.

Head Injury Protection

Deceleration is expressed in meters per second,² or "g," where one g is equal to the force of gravity on the earth's surface. The g force of an impact depends on initial velocity and available stopping distance.

Head tolerance to a focused impact (bone break strength) ranges from 30g for the nose to 100–200g for one square inch of frontal bone.⁴ The head can tolerate more diffuse impact forces of 300–400g without



Figure 4. British inventor W.T. Warren in 1912 demonstrating a spring-equipped helmet. This helmet saw considerable use in World War I (photo courtesy of Quadrant/Flight International).

skull fracture or concussion. Helmet designers endeavor both to insulate the head from penetrating injury and also to reduce global head deceleration forces to the 300g range.

The ideal flight helmet should weigh less than 4.4 lb, and the center of gravity of the helmet-head combination should match that of the unhelmeted head as closely as possible. A heavy or unbalanced helmet will rapidly cause fatigue or neck pain and could affect performance. The helmet should be as smooth and streamlined as possible, to avoid cockpit entanglements and reduce the effect of tangential impacts.

Apart from distributing the impact force and providing energy-absorbing substance, a good helmet fulfills a variety of other functions. Helicopters are notoriously noisy, and a helmet can protect hearing as well as facilitate communication. It also may serve as a platform for an oxygen mask or specialized night vision equipment.

Modern Flight Helmets

In the decade following World War II, head protection was not widely available for U.S. Army helicopter pilots. However, as accident statistics began to demonstrate fewer head injuries when aviators crashed wear-

ing locally procured helmets, it became evident that head protection was effective and necessary.

Table 1 depicts an evolution of the helicopter flight helmet over the past 35 years. New, specialized helmets with integrated visual displays (used by Apache pilots) are not included in this discussion.

The APH-5 Helmet. With head protection as the primary driver, the Army adopted the Navy's Aircrew Protective Helmet (APH-5) for wear in 1958 (Figure 2), although some Army pilots had been wearing this helmet since 1954.^{10,11}

The APH-5 provided impact protection by combining a compressible liner with a hard shell constructed of resin-stiffened layers of fiberglass. Under standard test conditions, a helmeted headform experienced less than 250g.¹² Separate foam sizing pads were provided in three thicknesses to facilitate custom fitting.

The retention system consisted of a padded nylon chin strap screw-secured to the shell on both sides and fastened via a snap. Due to limitations of this single-snap fastener system, chin strap strength was only 150 lb.

Although the APH-5 was, in general, well-received, aviators complained that the helmet was too hot, too

heavy, and too tight.¹³ These problems, combined with other design deficiencies, spurred the search for a replacement.

The SPH-4 Helmet. In the mid-1960s, the Army determined that the APH-5 provided inadequate hearing protection, particularly in the low frequency sound range (75–2,000 Hz). Subsequent tests of the Navy's newer sound protective helmet (SPH-3) proved it superior to the APH-5 in sound attenuation, earphone design, the suspension system, microphone, and ease of fit. After several modifications improving the crashworthiness and retention of the helmet, the SPH-3 was accepted by the Army as the SPH-4 (Figure 3).

The SPH-4 provides two layers of impact protection via a hard fiberglass cloth and resin shell and a high-density single-piece styrofoam liner. A third layer of protection includes a suspension system consisting of a leather-covered nylon headband with three intersecting crown straps attached to the shell with metal clips. Proper adjustment of the suspension

assembly provides a comfortable fit without head contact with any part of the styrofoam shell. During an impact, the nylon straps elongate (up to 22%) and the clips bend, providing impact attenuation prior to head contact with the styrofoam shell. Drop tests show that the SPH-4 limits head deceleration to 300g. Although this represents a 50g increase in transmitted energy compared to the performance of the APH-5, it is still below the 300–400g threshold for concussive injury.⁴

The retention system consists of a nylon/cotton assembly holding the earcups, chin strap, and nape strap, forming a circular harness around the neck. As with the APH-5, chin strap strength in early versions of the SPH-4 was limited to 150 lb because of a single-snap fastener. The chin strap comfort pad of the APH-5 was downsized to provide a closer fit for the SPH-4, and a maximum allowable chin strap elongation of 1.5 in improved helmet retention. The SPH-4 employs the M-87 microphone, which greatly reduces voice distur-

tion,¹⁴ and a single acrylic visor with plastic outer cover.

Studies showed that aviators preferred the SPH-4 over the APH-5 with respect to fit, comfort, noise attenuation, and the communication system.¹¹ As crash experience with the SPH-4 accumulated over the years, several improvements were made. For example, the chin strap was modified to improve helmet retention by using stronger material, and by installing two snaps on one side and a screw post attachment on the other.

The SPH-4B Helmet. Despite the overall success of the SPH-4, it did not provide ideal head protection. Army epidemiologists noted that helicopter crash victims wearing the SPH-4 were still at high risk for two principal types of head injury: concussion and basilar skull fracture. The latest upgrade to the SPH-4, termed the SPH-4B, greatly reduces the risk of these injuries. Global impact protection was improved by reducing the density of the polystyrene liner (to allow the foam

to compress more easily) and increasing the liner thickness (to increase stopping distance).¹⁵

The elevated risk of basilar skull fracture in SPH-4 wearers was traced to the rigid plastic earcups.¹⁶ One-fourth of all impacts to the SPH-4 occur to the earcup region, and the lack of energy attenuation in the earcup allowed excessive force to be transmitted to the base of the skull. The new SPH-4B includes a thinner plastic earcup and more liner foam along the sides of the helmet, allowing energy from a lateral blow to be dissipated by fracturing the helmet earcup.¹⁷

Other changes in the new SPH-4B helmet include a modified chin strap and yoke assembly to improve retention of the helmet, a thermoplastic liner to improve comfort and fit, and a Kevlar™ shell (Table 1). These modifications result in a new helmet that is .5 lb lighter than its predecessor, the SPH-4.

The SPH-5 Helmet. A civilian version of the Army's SPH-4B helmet is called the SPH-5. It is similar to the

SPH-4B in weight and performance, but the Kevlar shell of the SPH-4B is replaced with ballistic nylon and graphite (Table 1).

The Alpha Helmet. Developed by Helmets Limited of St. Albans, Great Britain, the Alpha helmet was intended to be used by helicopter pilots and fixed-wing pilots. The significant difference between this helmet and the SPH series is the foam liner, which is integral to the helmet shell, providing extra stiffness with minimal weight.¹⁸

Fixed-Wing Helmets. Helmets designed exclusively for use in fixed-wing aircraft should be carefully evaluated before purchase. Many of these lightweight helmets are designed to withstand ejection and windblast forces, but will not provide sufficient energy attenuation to prevent injury in a rotary-wing accident sequence. In addition, helmets designed for use in a fixed-wing aircraft may not provide sufficient protection from the low frequency noise often encountered in helicopter flight.¹⁸

Helmet Effectiveness

Although protective flight helmets were scorned by some early flight safety authorities,¹⁹ others were strong believers. Graeme Anderson, in his 1919 aviation medicine textbook,²⁰ reported that of 58 training accidents in his experience, student pilots were saved from head injury in 15.

"Over and over again the author has seen pilots thrown out who owe their escape from more or less serious head wounds, to their safety helmets." Most pre-World War I aviators, on the other hand, were unconvinced of their benefit.¹⁹

The early helmet developer often tested his own designs, sometimes before an amused and skeptical audience (Figure 4), and sometimes by hitting himself on the head with a mallet in the privacy of his laboratory.⁸ Modern helmet engineers use precisely calibrated drop towers and other devices to assess helmet performance. However, the most compelling evidence regarding helmet effectiveness is actual crash injury data.

Table 1
Characteristics of Helicopter Flight Helmets

Helmet Detail	APH-5	SPH-4	SPH-4B	SPH-5	ALPHA
Year Fielded	1958	1970	1991	NA	NA
Weight ^a	3.5 lb	3.3 lb	2.8 lb	2.8 lb	2.8 lb
Visor Type	Acrylic single	Acrylic single	Polycarbonate	Polycarbonate ^b dual	Polycarbonate dual
Shell Material	Fiberglass	Fiberglass	Kevlar graphite	Nylon/graphite	Kevlar graphite
Styrofoam Liner Thickness	0.5 in ^c	0.4 in	0.6 in	0.6 in	0.75 in
Suspension System	Leather-covered foam pads	Three-strip sling	Thermoplastic liner	Thermoplastic liner	Sling/pad
Impact Protection	250g	300g	160g	160g	180g
Chin Strap Strength	150 lb	150 lb	440 lb	440 lb	450 lb
Earcup Type	Eclipse-shaped soft foam	6mm flat flange rigid plastic	3mm contour rigid plastic crushable	3mm contour rigid plastic crushable	NA

^a Weight includes medium-sized helmet, visor, and communications assembly.

^b Single and dual-visor systems are available.

^c Liner is split into three sections.

^d Helmeted head impacts a flat surface from 5-ft free fall.

There have been two studies of helmet effectiveness in helicopter accidents—one in 1961 and the other in 1991. The first study examined the effect of the Army's APH-5 helmet on injury severity during the period 1957–1960.¹³ Fatal head injuries were found to be 2.4 times more common among unhelmeted occupants of potentially survivable helicopter accidents than among helmet-wearing occupants. The author credited the then-new APH-5 helmet with saving 265 lives during the study period.

The 1991 study compared crash occupants wearing the later helmet, the SPH-4, with unhelmeted occupants of severe, but potentially survivable helicopter accidents from 1972–88.²¹ In the crashes studied, the risk of fatal head injury was 6.3 times greater in unhelmeted occupants compared with those wearing the SPH-4 ($p < 0.01$). Unhelmeted occupants riding in the rear of the crash aircraft were at even higher risk of fatal head injury (relative risk=7.5; $p < 0.01$). This latter finding is particularly relevant because civilian flight medical personnel generally ride in the rear of the helicopter.

Since these studies are based solely on U.S. Army accident data, the issue of external validity should first be addressed, that is, can these results be applied to civilian aviation? Although much civil helicopter flying is obviously different from tactical military aviation (controlled airspace, high altitude, busy airports), some civilian flying is very similar. Since civil aviation injury data are lacking, it does appear reasonable to apply these military data to civilian helicopter scenarios with similar flight profiles.

Reluctance to Use Flight Helmets

Despite the acceptance of flight helmets in military helicopter aviation, and the recommendations of numerous safety agencies, the civilian rotary-wing community has been slow to embrace head protection and other aviation life support equipment, such as fire protective flight suits and flight gloves. In 1989 Kruppa reported in *JAMT* that only 13% of civilian

emergency medical services (EMS) aviation programs used flight helmets, and 29% used fire-retardant uniforms. Reasons cited for helmet non-use included bad public relations, high costs, and uncertain effectiveness.²² Hoffman and Shinskie reported in 1990 that helmet use had increased to 21%, noting that 5% of responding programs reported at least one in-flight injury that could have been prevented by helmet use.²³

These concerns about public relations and the patient's emotional state, while well-intended, ignore three things: (1) a regular aircrew member's level of risk over a career spanning several years is far higher than the patient's risk during a single flight; (2) if there should be a crash, conscious flight crewmembers will be of better use to the patient than would an unconscious crew; (3) by providing a headset for the patient,

reassuring communication can actually be enhanced.²⁴

Conclusions

Throughout history, man has worn head protection in response to the threat of head injury. Such armor has limitations and drawbacks, but in helicopter aviation it is effective and worthwhile. All personnel regularly participating in helicopter flight (civilian or military) should be equipped with protective headgear.

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The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official authority. ■

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