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SPH-4 U.S. Army Flight Helmet Performance 1983-1987

By

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Injury data was obtained from the U.S. Army Safety Center for the occupants of U.S. Army aircraft who were wearing aviator helmets when involved in duty-related aircraft accidents from the period beginning in June 1982 and ending in October 1987. The injury data was correlated with the physical condition of the helmets involved which had been obtained by the U.S. Army Aeromedical Research Laboratory under the Aviation Life Support Equipment Retrieval Program. The helmet performance was evaluated with regard to current injury prevention capabilities and potential improvements for future helmet designs. All helmets involved were involved in aircraft accidents except one SPH-4 which had been damaged by small arms fire. Keywords:

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Historical background

There have been many previous reviews (Reading et al., 1984; Schneider and Walhout, 1962; Slobodnik and Nelson, 1977; and Slobodnik, 1980) of U.S. Army aviator helmets since the introduction of the Aviator Protective Helmet No-5 (APH-5) in October 1959. The reader will have to read these reports with care to glean all the available information. Nevertheless, certain points always are present and specific features of helmet design have been criticised frequently. Indeed, some of these areas still remain largely uncorrected. A review of Army APH-5 performance (Schneider and Walhout, 1962), based on data obtained in the late 1950s, highlighted the following areas which were considered to require attention:

a. The shell has many protuberances, including visors and visor covers, which are points of concentration, snagging, and initiation of fractures.

b. The energy absorbing liner is not used sufficiently in areas where it is maximally needed, i.e., temporal and frontal regions.

c. The earphones are too bulky, displacing energy absorbing material from the temporal areas, and allowing the direct transmission of impact force to this vulnerable area.

d. The retention system is weakened by seams and screw attachments. It is often adjusted incorrectly and the nape strap has a tendency to slip off its anchorage point beneath the nuchal notch, allowing helmet rotation or loss to occur.

The recommendations given, based on the findings of the above study, included the following:

a. The helmet surface should be as clean as possible and any unavoidable additions should be confined to the rear of the helmet which is rarely involved in significant impacts.

b. Visors should protrude as little as possible in order to avoid snagging and stress concentrations.

c. The liner should be of an increased thickness and be designed to be maximal in those areas where impacts are most likely to occur.

d. The retention system should be positive and secure to the limits of human tolerance and should be simple to use. An improved suspension system was suggested which incorporated an integrated chin/nape strap design, similar to that discussed more recently by Palmer and Haley (1988).

A further report dealing with U.S. Army experience with the APH-5 (USABAAR Report HF4-61) comments on the problem of helmet retention which was prevalent then. However, it also contains one of the few references to the documented improvement in head injuries and head injury fatalities subsequent to the introduction into service of the APH-5 in October 1959. Prior to the introduction of helmets, 20 percent of all occupants involved in rotary wing accidents suffered from severe head injuries and 3.8 percent resulted in fatalities. After the introduction of helmets, the fatalities had dropped to 1.4 percent of all serious head injuries and there was a marked preponderance of fatal head injuries among passengers who were not wearing any head protection because many of the helicopters at the time were equipped only with lap belt harnesses. While it is undoubtedly true the current SPH-4 and IHADSS helmets are great improvements to the APH-5, many of the areas alluded to above remain unresolved and, in certain cases, the demands of new technology have served to exacerbate the situation.

Introduction

In 1972, the U.S. Army Aeromedical Research Laboratory (USAARL) established the Aviation Life Support Equipment Retrieval Program (ALSERP). The purpose of this program is to evaluate the efficiency of protective equipment in the aircraft accident environment and to use this data to improve and modify current equipment and develop new design criteria for the future. In accordance with Army Regulation 95-5 and Department of the Army Pamphlet 385-95, all life support equipment (LSE), which is in any way linked with the cause or prevention of injury in aviation accidents, is shipped to this laboratory for analysis. The ALSERP program also fulfills the U.S. Army's commitment to Air Standardization Agreement No. 61/6 which provides guidelines for the collection and analysis of data concerning aircrew helmets damaged in service. This report concerns data obtained from 146 aircrew helmets during the period June 1982 - October 1987. The majority of the helmets retrieved (135) were Sound Protection No.4 (SPH-4). Also studied were six integrated helmet and display sighting system (IHADSS) helmets and five sound protection helmets No. 3C (SPH-3C) which were obtained from U.S. Navy helicopter accidents. All of the helmets studied had been involved in aircraft accidents or incidents and had been forwarded to USAARL for study. The data obtained refers to information gleaned from all helmet types, but a separate section has been devoted to the IHADSS helmet due to its novel characteristics. This report is contiguous with that of Reading et al. (1984) and should be read in conjunction with it. To this end, a similar format has been maintained, as far as possible.

The design of aviation helmets for helicopter pilots now is at a crossroads. The traditional priorities of helmet design, namely impact and sound protection, are under increasing fire from other demands such as imaging, sighting, and visual protective devices. A compromise surely will result, but hopefully, this will be a solution based on the facts obtained in studies such as this one.

Methods and materials

The Army's standard flight helmet, SPH-4, replaced the Navy-developed APH-5 in the 1970-1973 period and has been in continuous use since. Components and features of the SPH-4 are shown in Figures 1, 2, and 3. Pertinent features of the SPH-4 are:

a. Shell - 2.5 mm thick epoxy resin and fiberglass cloth.

b. Liner - Energy-absorbing 0.5 inch thick expanded poly-styrene with a density of 4.5 lbs cubic feet.

c. Suspension - With two standard shell sizes, the adjustable headband and crown straps provide easy fitting for most wearers.

d. Earcups - Large "rotatable" design provides easy fit and good noise attenuation. The large volume required to obtain satisfactory low frequency attenuation does, however, considerably increase the width of the helmet.

e. Acoustic sealing - Tension cross straps in the shell provide inward pressure on earcup seals for sealing and easy fit for most wearers.

f. Ventilation - Natural air circulation occurs above the head as shown in Figures 1 and 2.

The SPH-4, with reasonable fit made possible by the adjustable earcups and sling suspension, provides good noise attenuation, especially against low frequency noise (Bynum, 1968). The quality of the SPH-4 is controlled by military drawings, specifications, and standards MIL-H-43925 (1975). In addition, the acoustic, impact, and retention characteristics of the helmet are verified for each new procurement lot. The SPH-3C differs in that it is manufactured with a Kevlar shell and is fitted with a dual visor system. The pertinent features can be obtained by reference to Table 1, which also includes details of other helmet types mentioned in the text. Also shown are details of the SPH-5 helmet which was developed by the Gentex corporation and offered for sale in 1986.

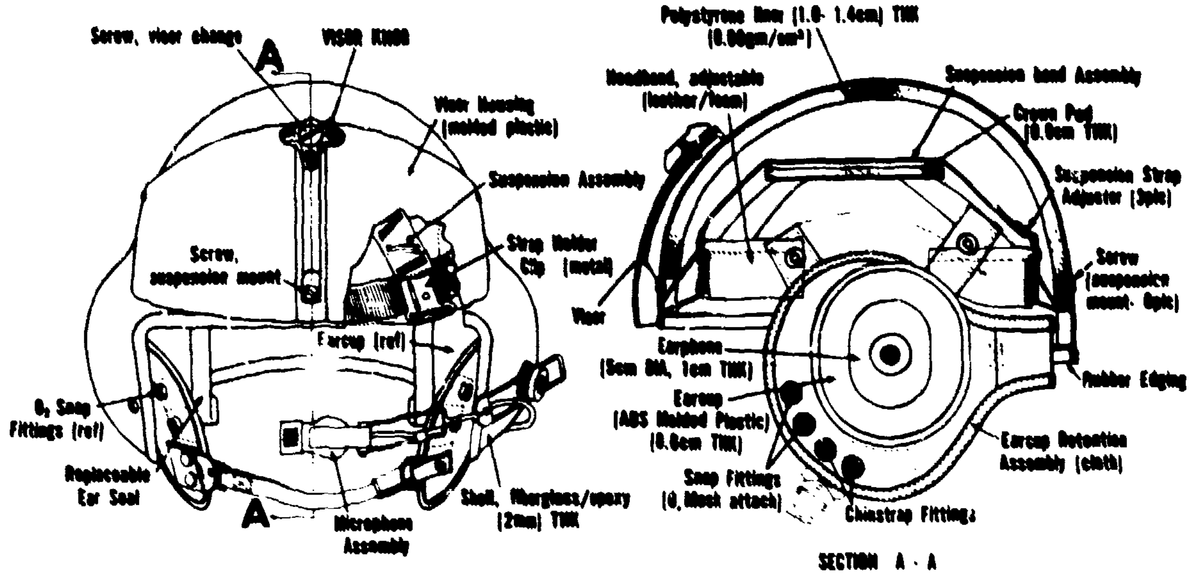

Figure 1. SPH-4 helmet assembly.

Figure 2. Frcnt and profile views of cutaway SPH-4.

Figure 3. Liner coverage provided by SPH-4.

Helmet analysis

The analysis that follows applies to all the 146 helmets studied. Where necessary, differences between the various helmet types are explained and the IHADSS helmet also is discussed separately. A total of 146 helmets from 71 separate accidents which occurred during the period June 1982 - October 1987 are considered in this report. Cross reference with the U.S. Army Safety Center, Fort Rucker, Alabama, reveals this represents a return rate of almost 77 percent. Many of the helmets not represented were cases involving catastrophic damage from totally nonsurvivable accidents. All helmets except two were from rotary-wing accidents; the latter were from fixed-wing (OV-1 Mohawk) aircraft. Table 2 indicates the aircraft type and seat location involved.

Table 1

Helmet descriptive data

Component	Helmet type			
Helmet	SPH-3C	SPH-4	IHADSS	SPH-5"
Helmet weight (lb) with visor and communications	Med 4.1	Med 3.3	Small 3.95 Large 4.1	Large 2.7
Suspension type	Sling	Sling	Sling-liner-basket	TPL
Shell material	Epoxy and Kevlar	Epoxy and fiberglass	Kevlar and graphite	Epoxy and Kevlar
Liner foam material Density lbs/cu ft	Polystyrene 4.5	Polystyrene 4.5	Polystyrene 3.0	Polystyrene 2.5
Liner thickness (in)	0.50	0.50	0.75	0.63
Retention harness type	Chinstrap-to-earcup-to shell	Chinstrap-to-earcup-to-shell	Chinstrap-to-basket-to-shell	Chinstrap-to-earcup-to-shell
Napestrap	Napestrap-to-earcup-to-chinstrap	Napestrap-to-earcup-to-chinstrap	Napestrap-to-basket-to-shell	Napestrap-to-earcup-to-shell
Chinstrap strength	280 lb	280 lb	280 lb	280 lb
Chinstrap release	2 snaps	2 snaps	2 snaps	2 snaps

Table 2

Aircraft type and seat location of wearer

Aircraft type	No.	Seat location of wearer (where known)	No.
UH-1	42	Forward facing	119
UH-60	35	Side facing	9
AH-1	23	Rear facing	5
OH-58	20	Ground	2
AH-64	8	Pilot/copilot	104
CH-53	6	Crew chief	19
CH-47	5	Passenger	15
OV-1	2		
RG-8A	2		
OH-6	1		
T-55	1		

Each helmet was analyzed by the ALSERP committee consisting of a flight surgeon, who was also a rated helicopter pilot, and specialists in the fields of engineering, physiology, and life support equipment. All data was entered onto a form specially designed for this purpose which is reproduced in Appendix A. Data then was entered into a simple, easy to use, database for later analysis and correlation.

The form is intended to record data in four areas:

a. General information about the accident (questions 1-6, 10-11, 80-84).

b. Information about the helmet and its performance (questions 7-9, 15, 20, 32, 40, 47, 54).

c. Information concerning the aviator's injuries (questions 12-14, 16-19, 21-31, 43-46).

d. Damage to the various helmet components and causes of such damage (questions 33-39, 41-42, 48-53, 55-79).

Data for areas 1, 2, and 3 normally were obtained by reviewing the official report of each accident, DA Form 2397, "Technical Report of U.S. Army Aircraft Mishap." The inspection team was able to communicate directly with medical personnel or other investigators who were involved in a particular accident. All head injuries were graded according to severity using the "Abbreviated injury scale" (AIS) (Joint Committee of the American Association for Automotive Medicine, 1980) as a guide. The AIS system was used to quantify a broad range of head injuries into categories of varying severity. The details of this code were updated in 1980 and a revised scale issued. A summary of the 1980 revised scale is shown in Table 3. The AIS scores were recorded in both the new and the old formats in order to retain a degree of compatibility between the old and new data. In practice, little significant difference was noted in the grading of head, neck, and face injuries. A note of caution has to be introduced here, as the AIS scale relies on an accurate description of the victim's injuries, and this was not always available to the investigators at USAARL. In particular, it was difficult to ascertain the degree of concussion sustained and the subsequent time of unconsciousness or amnesia. It should be noted the AIS referred to here pertain to head injuries alone - they are not overall AIS values.

Table 3

Summary of the abbreviated injury scale (AIS) codes 1980

0	No injury
1	Minor
3	Moderate
4	Severe
5	Critical
6	Maximal injury, virtually unsurvivable

Each helmet wearer was placed into one of three categories based on head injury and helmet performance. The survivable category consisted of those individuals who had either no head injuries or nonfatal head injuries. Individuals with fatal injuries were placed in either the nonsurvivable category or the potentially survivable category. Potentially survivable head injury cases were those in which the inspection team was convinced an improved helmet of feasible design (generally one with improved energy absorption and retention capability) would have lessened or prevented the individual's injury and thus prevented the fatality. Nonsurvivable cases were those in which it was determined that no feasible improvement in the helmet would have been of benefit to the wearer under the circumstances of the accident. It is the survivable and potentially survivable cases which are the most useful indicators of productive alterations in future helmet designs.

Helmet damage evaluation

Each helmet was examined thoroughly at USAARL to determine the number, severity, and location of all impacts due to the accident. Impacts were defined as any forceful contact of the external shell of the helmet with environmental objects sufficient to cause either external surface changes, compression of underlying foam, or both, during the course of the crash sequence. Helmet damage was catalogued according to location, type of shell damage, approximate amount of foam compression, and shape of impact surface.

a. Location. The helmet was divided into five large areas: crown, front, rear, left side, and right side (Figure 4). (Smaller subdivisions were not used in the current analysis.) As many as five impacts per helmet were cataloged by location in these five areas. A template helmet was used and all impact locations were assigned based on these standards.

b. Shell damage. Shell damage was recorded qualitatively for each impact area. Damage was described using the following terms:

(1) Fracture: Helmet shell was broken through (severed or separated).

(2) Puncture: A small puncture with evidence of a sharp object penetrating through the shell of the helmet.

(3) Material missing: Shell material was torn out, usually due to extreme deformation or tangential impacts.

(4) Delamination: Shell laminae separated; i.e., the cement binder between the cloth piles failed. This is indicative of considerable inbending which causes shear stresses between laminae.

(5) Gouge: A thin deep section of paint and shell carved out by a sharp object.

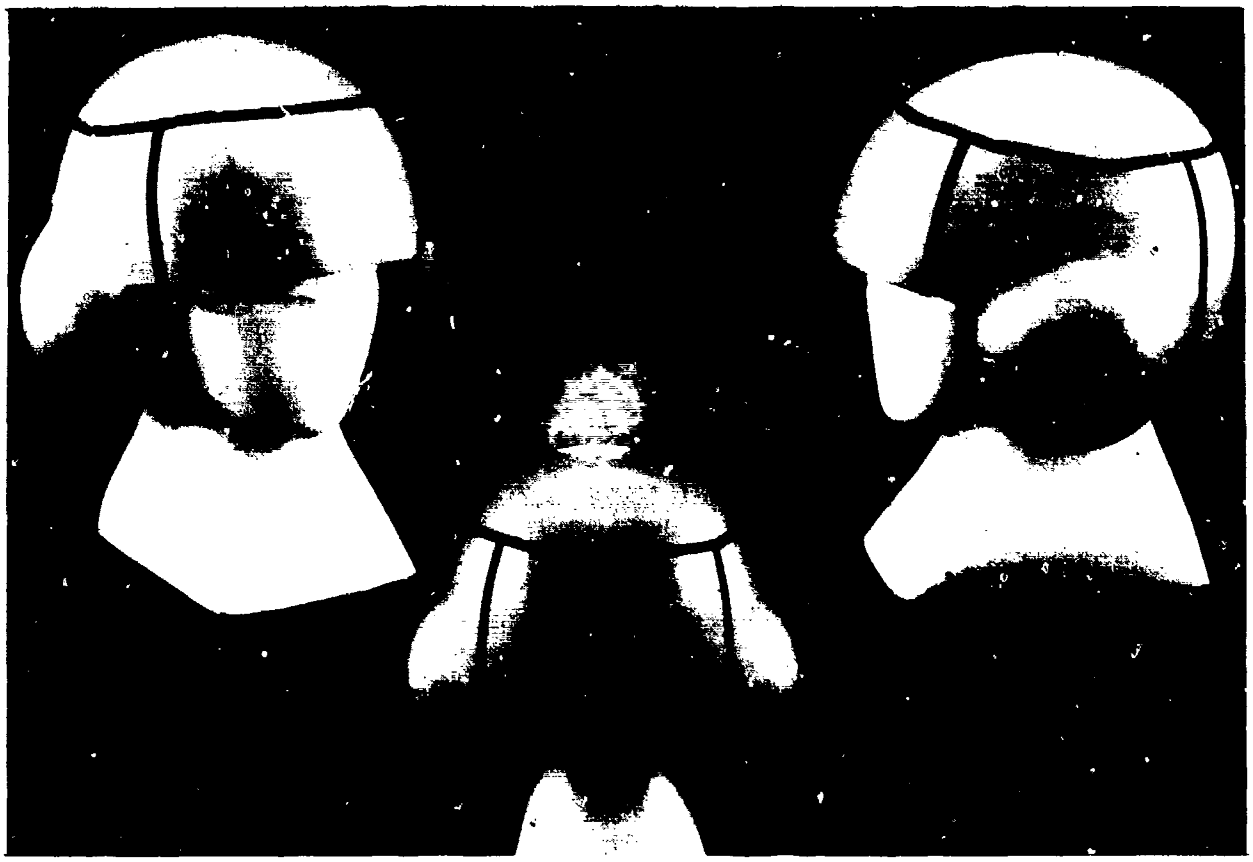

Figure 4 . Division of helmet to determine impact location.

(6) Abrasion: A wide portion of shell worn away due to dragging across a rough surface.

(7) No damage: No damage of any consequence to the shell, but there may be evidence of impact pressure to the surface (e.g., paint scraped or discolored; traces of the substance of the impact surface are present).

c. Foam compression. Foam compression was determined with a measuring device as shown in Figure 5. Areas of compression were measured and the maximum amount of compression was recorded for each impact. Earlier work (Slobodnik and Nelson, 1977) had shown that the liner tended to rebound after compression so that the final thickness was rarely greater than 40 percent of the uncompressed thickness after 72 hours. This was true even if the initial compression had been greater than 90 percent. Since most of the helmets were shipped to USAARL at least 1 week after the accident, any residual foam compression in our ALSERP material which approached 50 percent was considered a maximal compression.

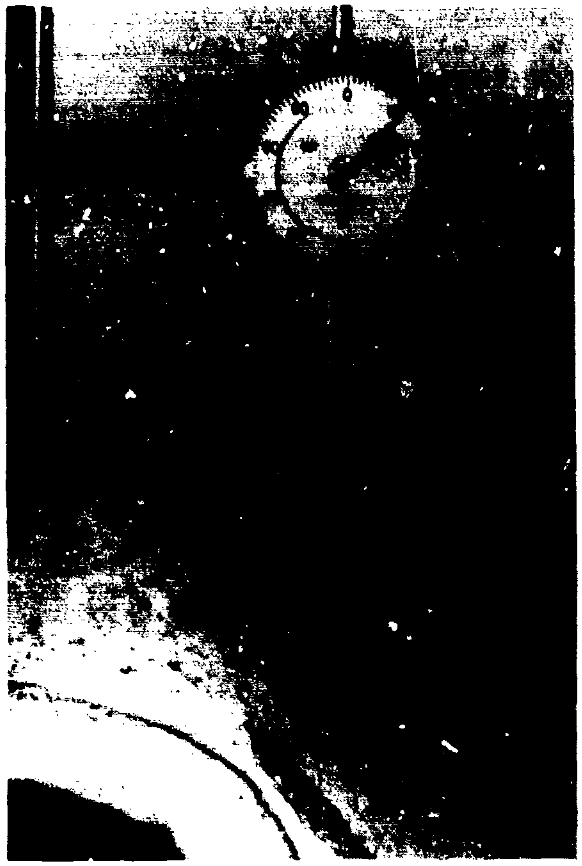

Figure 5. Dial gage arrangement to measure foam thickness.

d. Shape of impact surface. Impact surfaces were described as one of the following:

(1) Flat: Consisting of a roughly planar surface.

(2) Concave: Having a hollowed-out and rounded surface. This is typical of impacts with aluminum sheet metal surfaces which mold to the shape of the helmet such as the roof of the aircraft.

(3) Rod: A cylindrical object of 3 cm or more in diameter encountered perpendicular to its axis.

(4) Box corner: A three-sided, pyramid-shaped surface encountered roughly at its apex.

(5) Wedge: A surface approximating the intersection of two planes encountered roughly along the line of intersection of the planes.

(6) **Hemisphere:** A nearly spherical or rounded surface with a radius of 5 cm or more encountered roughly perpendicular to its surface curvature.

(7) Unknown: A surface which did not puncture the helmet shell and which inflicted blunt damage that was indeterminate between that seen with the flat and concave types of impact surfaces.

Results

A total of 146 helmets were reviewed along with the accident and injury data available for each case; 75 cases were classified as survivable, 15 as potentially survivable, and 38 as nonsurvivable. Fifty-five of these cases resulted in a fatality and 109 individuals were recorded as being the victims of head, face, or neck injuries.

Object struck

In a number of accidents, the nature of the object struck and causing the helmet damage had been noted. In many instances, this was not possible due to the inherent difficulties of aircraft accident investigation. The known objects are listed in Table 4.

Table 4

Object struck

Object struck	No. of occasions
Telescopic sighting unit (AH-1)	7
Seat armor	7
Glare shield/instrument panel	5
Canopy	3
Tail rotor	3
Circuit breaker panel	2
Miscellaneous known causes	10

Location of most severe impact

The location of the most severe impact was assessed in all those cases where helmet damage was not so extensive as to preclude this. Damage to the frontal area of the helmet is, of course, modified by the presence of the visor cover and the visor, and significant damage to this area has been included in the analysis. The dissimilar nature of the visor and visor cover material render it difficult to assess whether the impact concerned was the primary one, when compared to the impacts sustained by the rest of the helmet. Figure 6 demonstrates the type of visor damage often found. In this case, the Cobra helmet has a metal visor which has received major impact damage. Table 5 lists the location of the most severe helmet impact and includes those cases where the visor, or visor cover, were considered to be the site of the major blow. On those occasions when impacts were of equal moment, or damage spread to adjacent helmet areas, then both areas were included in the data.

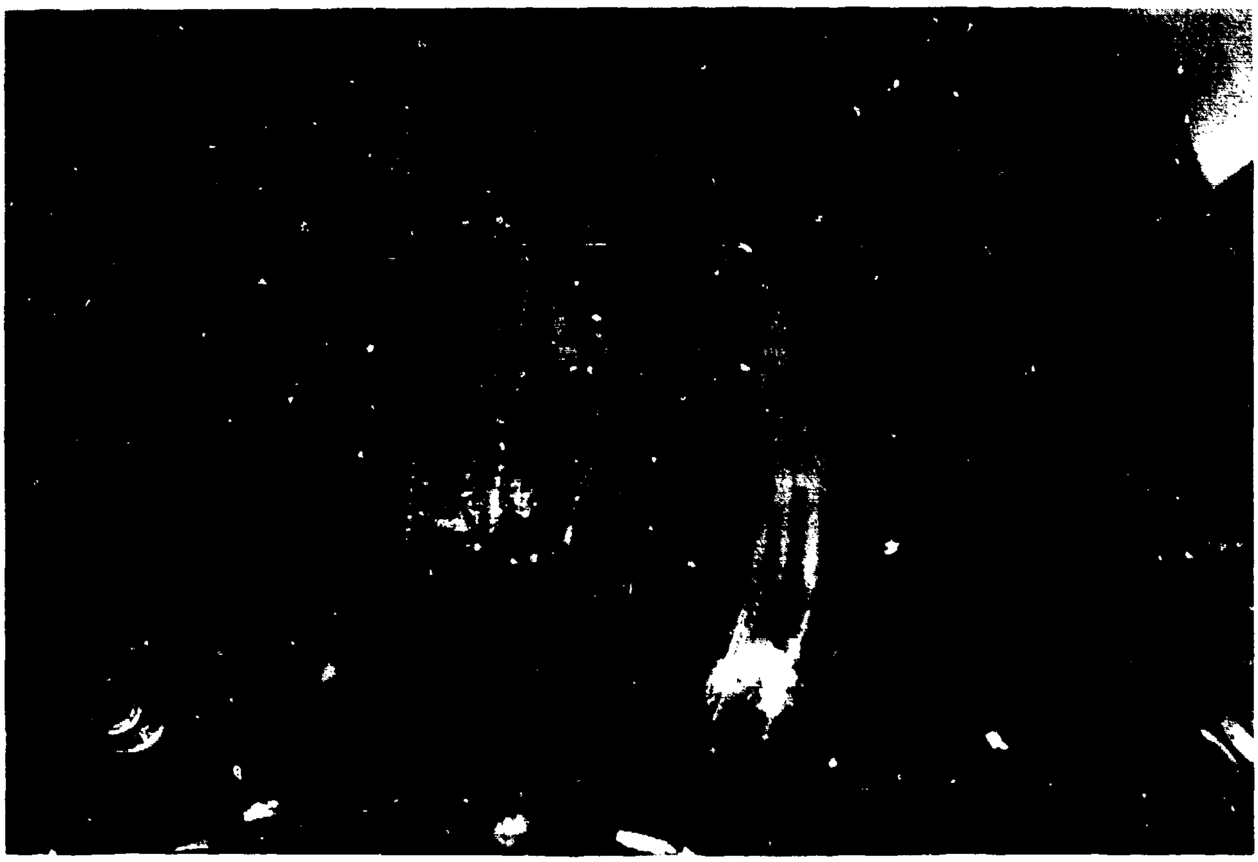

Figure 6. Damage to visor cover of Cobra helmet.

Table 5

Location of the most severe impact

Area of helmet	No. of occasions	Percent of all impacts
Sides	49	30.1
Visor/visor cover	47	28.9
Crown	41	25.0
Front	14	8.6
Rear	12	7.4

Impact surface

The impact surface shape encountered in the most severe impact are recorded in Table 6. The AIS 1980 scores relevant to each blow also have been included. Those accidents which involved catastrophic helmet damage have been excluded from the analysis.

Type of damage sustained by helmet

This was recorded as being an abrasion, delamination, fracture, gouge, missing material, or puncture. These terms already have been defined earlier. The type of damage sustained is recorded in Table 7.

Number of impacts per helmet

The number of impacts per helmet is recorded in Table 8. Some helmets had more than one impact and others were damaged so severely that estimation of the number of impacts was impossible.

Table 6

Impact surface of the most severe impact

Impact surface shape	AIS 1980							Total	Percent
	0	1	2	3	4	5	6		
Flat	5	6	5	4	2	1	15	38	35.2
Concave	5	3	5	0	0	0	3	16	14.8
Wedge	0	3	2	2	0	1	2	10	9.3
Rod	1	1	3	0	0	0	2	7	6.5
Box corner	3	0	2	1	0	0	1	7	6.5
Hemisphere	1	0	0	0	0	0	4	5	4.6
Unknown	2	7	4	4	1	1	6	25	23.1
Total								108	100

Table 7

Type of damage sustained by helmets

Type of damage	Percent
Abrasion	39.7
Delamination	22.4
Fracture	21.3
Gouge	10.2
Missing material	5.0
Puncture	1.4

Table 8

Number of impacts per helmet

No. of impacts	No. of helmets	Percent total
0	33	23.0
1	27	18.9
2	32	22.4
3	20	14.0
4	26	18.2
5	05	3.5
Total	143	100.0

Clip damage

The SPH-4 helmet retention system is attached to the helmet by a series of six clips which attach to the periphery of the shell. These clips, fortuitously, tend to deform under an applied load (Figure 7). Unpublished work from USAARL indicates an applied load of at least 60 lbs is required to bend one of these clips.

Their location and distribution are such that only a vertically applied blow to the crown, front, or rear of the helmet will result in their deformation.

Clip damage occurred on 68 occasions in the present series and, of these, 55 were due to major crown or frontal impacts. The remainder were caused by secondary impacts to the same areas with the main impact being to the sides of the helmet.

Figure 8 illustrates the distribution of clip damage and demonstrates the more extensive damage associated with non-survivable or fatal accidents. Nevertheless, almost 10 percent of survivable accidents had clip damage which required an applied load of at least 300-360 lbs.

Figure 7. Severely deformed suspension clip on SPH-4 helmet.

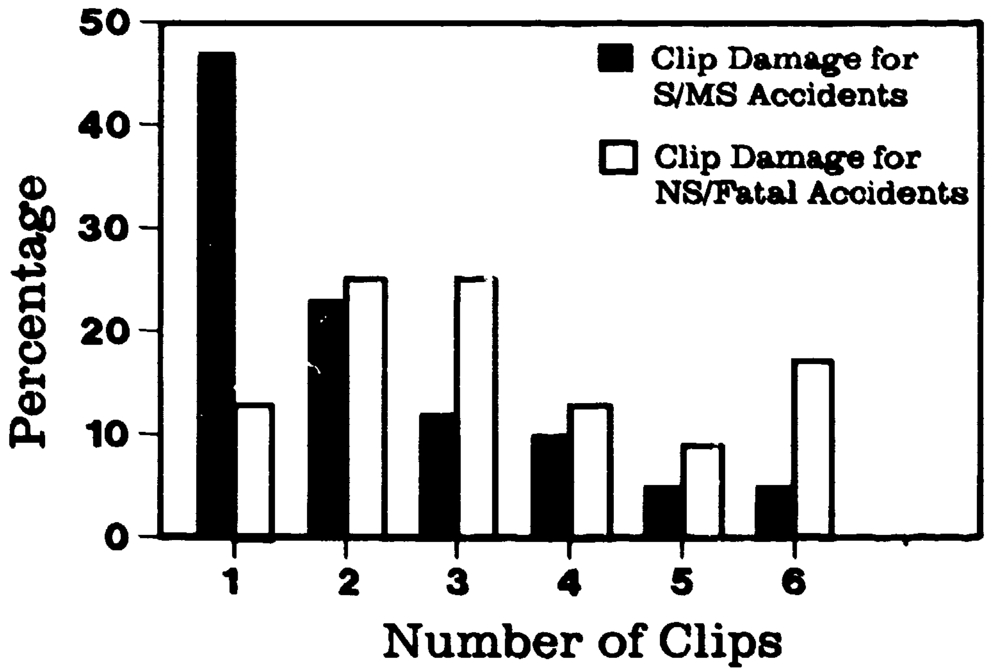

Figure 8. Clip damage distribution for SPH-4 helmets, comparing survivable/marginally survivable (S/MS) accidents with nonsurvivable (NS)/fatal accidents.

Earcup damage

The prevalence of earcup damage in previous studies (Shanahan, 1985) and the high incidence of severe damage to the side of the helmet prompted a careful study of such impact data to be undertaken in the present analysis. Generally, the damage either was minor consisting of only discoloration to the earcup where stresses have exceeded the elastic limit of the earcup material, moderate where there was minor deformation or cracking, or severe where gross deformation or fracture occurred. Figure 9 portrays the type of damage commonly seen and Table 9 records the factual information.

Both earcups were involved in 16 helmets and the left and right cups were damaged on 15 and 13 occasions, respectively. The AIS 1980 distribution for those helmets where earcup damage was recorded is presented in Figure 10.

Visor position

Two comparisons were made of visor position and the degree of injury sustained. One included all 146 cases and compared the fatality rates for those known to be wearing the visor up or down, or were wearing night vision goggles (NVGs). The other included only those cases where facial injuries were recorded. The results are shown in Table 10.

Head injury distribution

The distribution of head injuries in terms of severity as described by the AIS 1980 system are depicted in Figure 11. This compares the AIS distribution of survivable and potentially survivable cases with that for all cases including nonsurvivable accidents. As already explained, AIS values range from 0 (no injury) to 6 (currently considered untreatable).

Type of head, face, and neck injuries sustained

The injuries sustained by the individuals involved in the accidents are recorded in coded form on DA Form 2937. Obviously, these codings depend on the interest and accuracy of the flight surgeon in charge of each case. In cases of severe multiple injuries, some of the more minor injury specifics will be omitted from the report. As far as is possible, Figures 12, 13, and 14 represent the major types of injury involved, the number of cases, and the percentage of total injuries in all cases, survivable, potentially survivable, and nonsurvivable/fatal cases. The latter category includes those instances where a fatality occurred in an otherwise survivable/potentially survivable accident.

Figure 9. Example of a damaged earcup.

Table 9

Type of earcup damage

Damage	No. involved	Percent
Discoloration	18	30.5
Distortion	14	23.7
Minor fracture	11	18.6
Major fracture	16	27.0

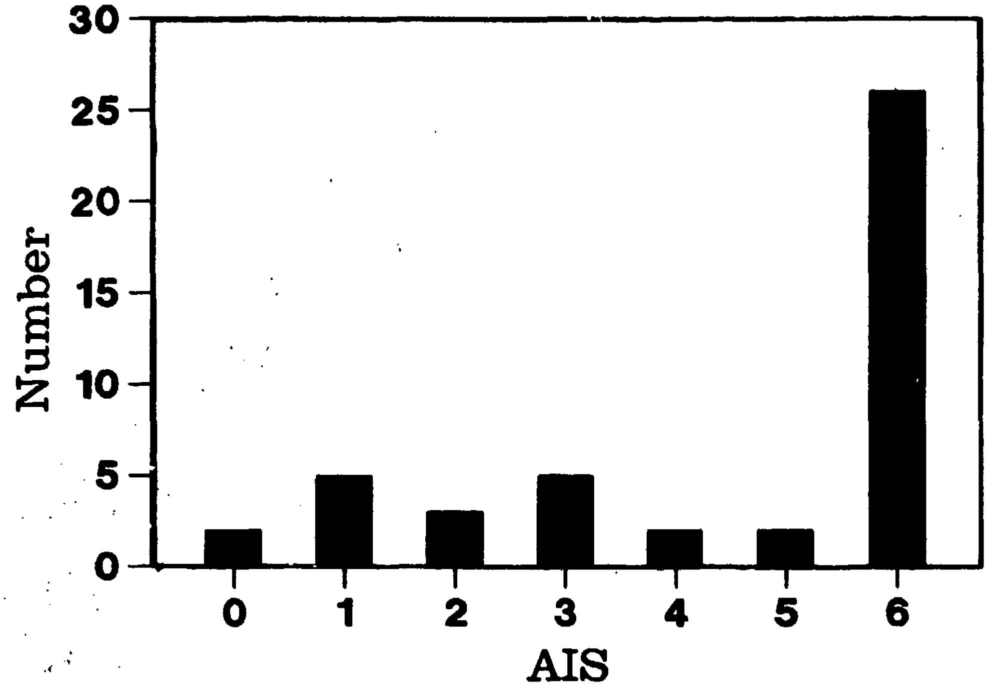

Figure 10. AIS 1980 distribution for helmets with earcup damage.

Table 10

Fatalities/facial injuries related to visor position

Visor position	All cases			Facial injury cases		
	No. of fatalities	Total no.	Percent fatal	No. of fatalities	Total no.	Percent fatal
Up	24	81	29.6	7	32	21.8
Down	6	23	26.0	2	9	22.2
Unknown	12	23	52.2	0	2	0.0
NVGs	10	19	52.6	3	7	42.8
Total	52	146	35.6	12	50	24.0

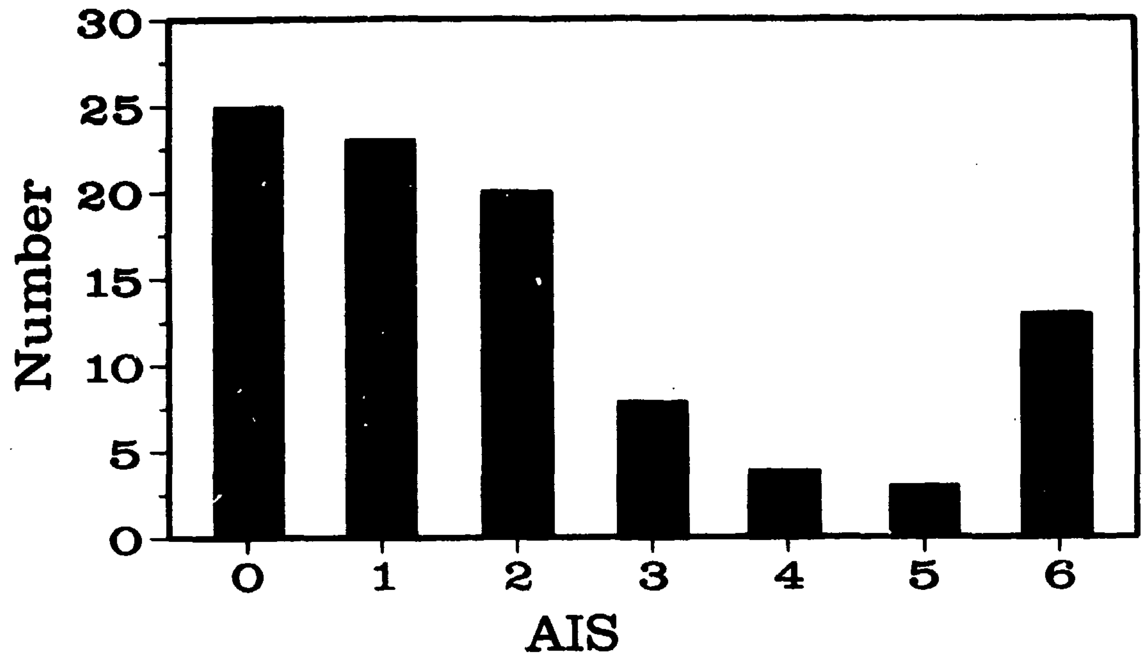

Figure 11. AIS 1980 distribution for survivable/ marginally survivable cases.

Unconsciousness or amnesia (retrograde or antegrade) were recorded only in 19 instances and all of these involved survivable or potentially survivable accidents. None resulted in a fatality. Periods of unconsciousness ranged from 1 minute to 96 hours and the period of amnesia ranged from 3 minutes to 48 hours. These data are shown in Figures 15 and 16. It was not possible to divide the period of amnesia into antegrade and retrograde types due to lack of precise detail on the DA Form 2937. The AIS distribution for those cases with recorded periods of unconsciousness or amnesia is shown in Figure 17.

Head injury related to helmet retention and helmet rotation

Figure 18 compares the AIS 1980 distribution of those helmets in which rotation or loss occurred and those cases in which the helmets are recorded as having been retained with little or no rotation.

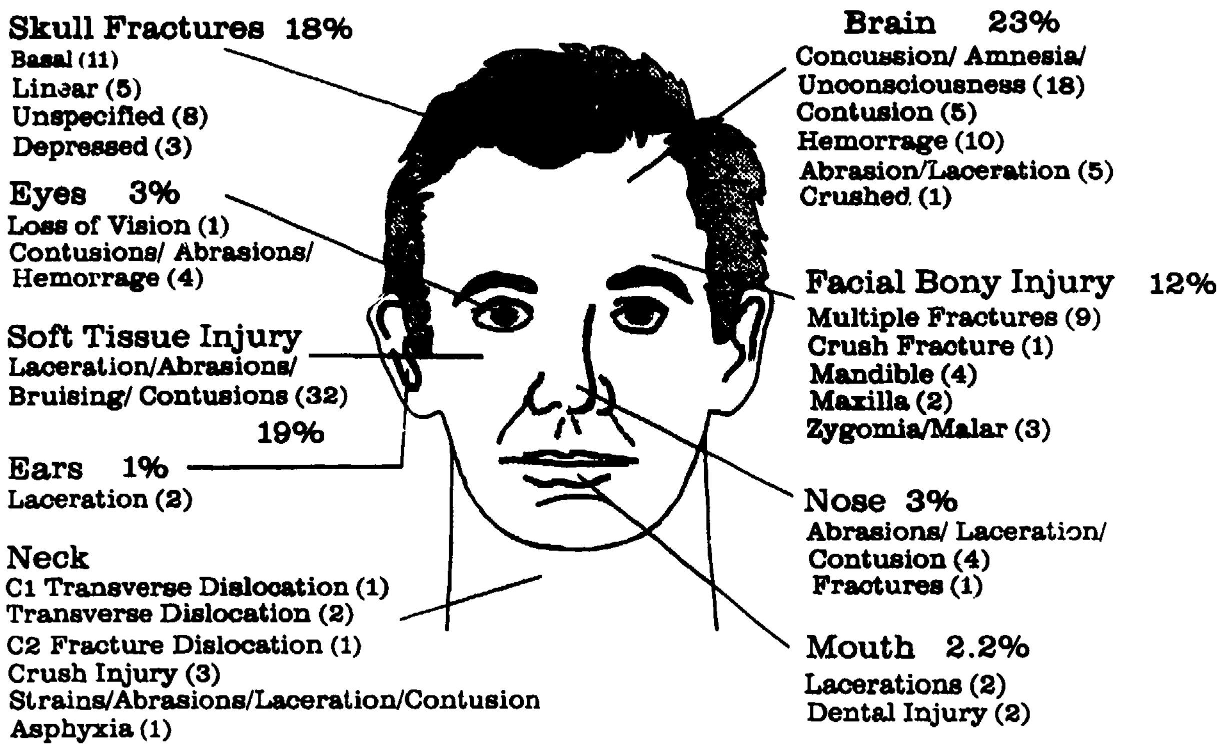

Figure 12. Head injury distribution - all cases.

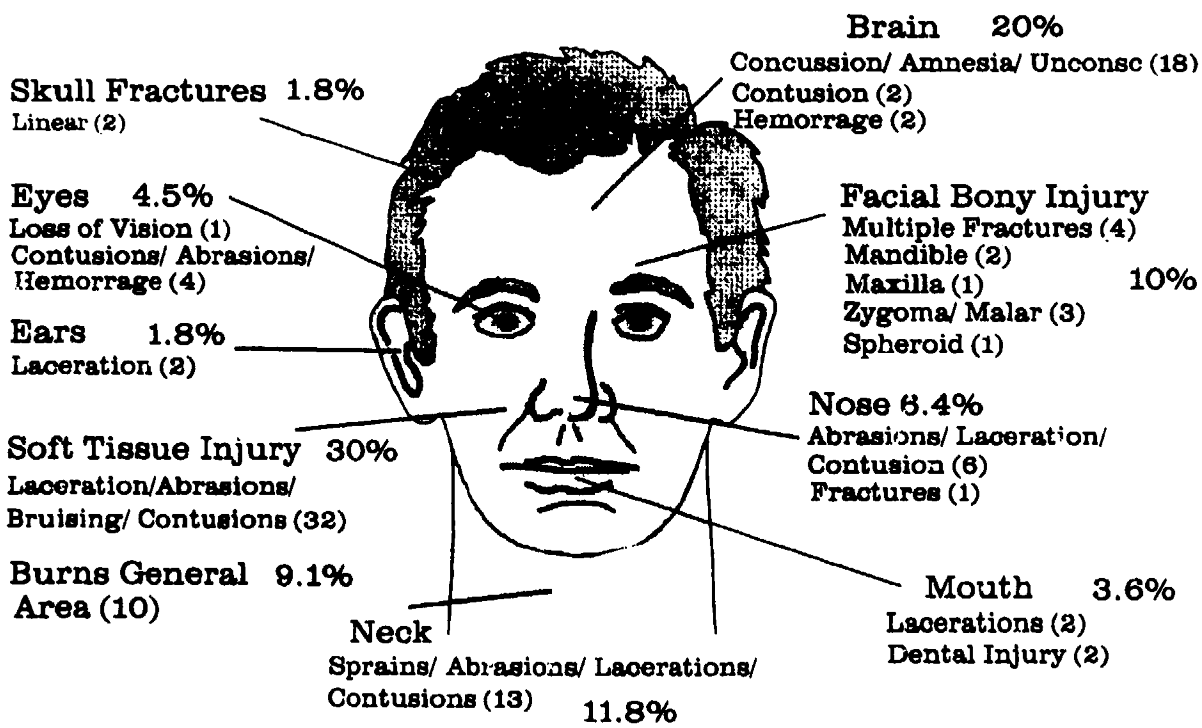

Figure 13. Head injury distribution - survivable and potentially survivable cases.

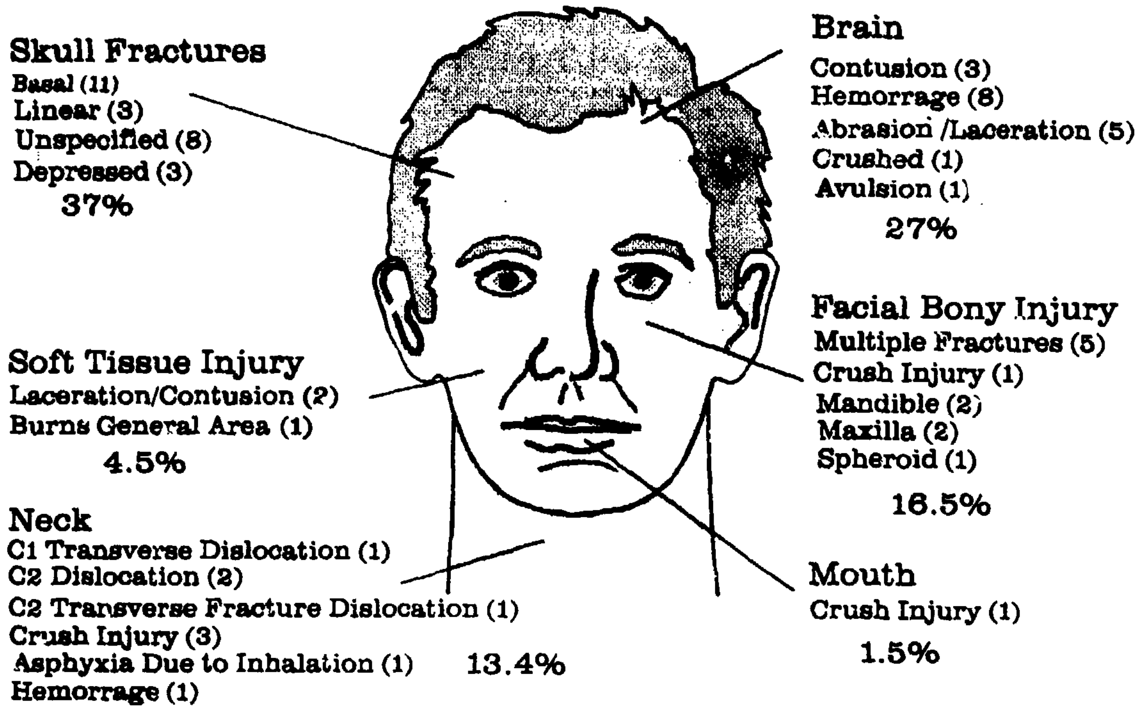

Figure 14. Head injury distribution - nonsurvivable and fatal cases.

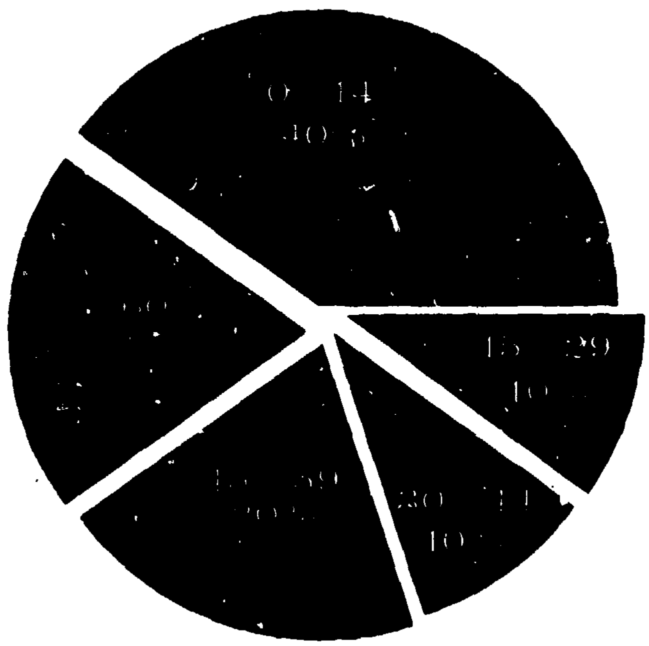

Figure 15. Periods of unconsciousness in minutes.

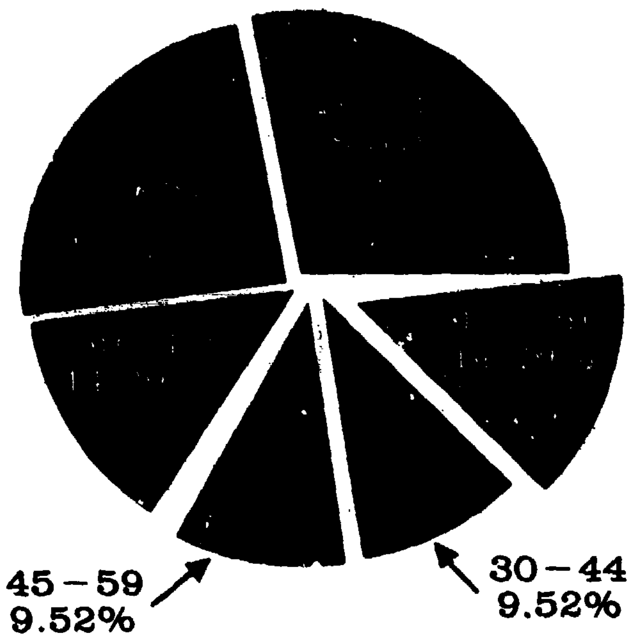

Figure 16. Periods of amnesia in minutes.

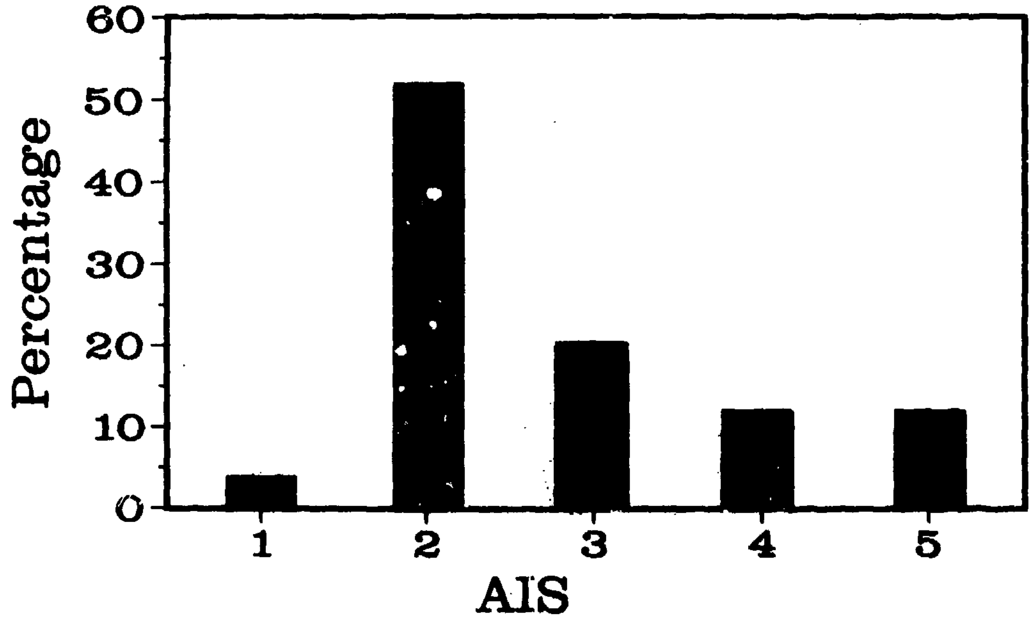

Figure 17. AIS 1980 distribution for those cases with recorded periods of unconsciousness or amnesia.

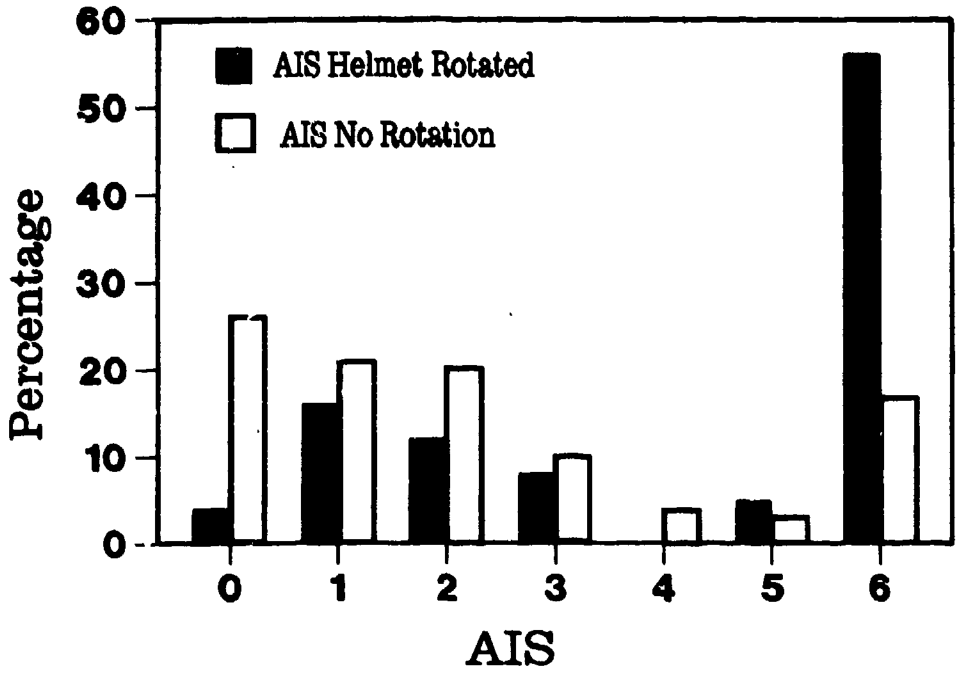

Figure 18. AIS 1980 distribution related to helmet rotation.

Foam compression and head injury

The relationship between foam compression and the degree of head injury sustained is shown in Table 11. These data exclude all cases in which the helmets were undamaged, no reliable information was available, or in which the only major impact involved the lateral aspect of the helmets where the foam liner is lacking.

Protective effect of helmets in aircraft fires

There were six recorded cases where cockpit fires occurred and the helmets served to protect the individual from the worst of the burn damage. The styrofoam liner typically only exhibited minor heat damage along the periphery, but had not melted or caused any direct thermal injury. Burns involving the head area always were confined to the unprotected facial and neck areas.

Table 11

Number of cases with head injuries for different foam compressions

Head injury AIS 1980	Foam compression (percent)							Total cases
	0	1-10	11-20	21-30	31-40	41-50	>50	
AIS 0	4	4	0	1	0	1	0	10
AIS 1	5	7	1	1	1	1	2	18
AIS 2	4	1	4	4	3	2	0	18
AIS 3	1	1	1	3	1	1	0	8
AIS 4	1	1	2	0	0	1	0	5
AIS 5	0	0	1	1	0	0	0	2
AIS 6	1	3	4	3	5	5	7	28
Total cases	16	17	13	13	10	11	9	89

Discussion

Table 5 clearly shows that if blows to the visor and visor cover are included, then over 37 percent of all major impacts involve the frontal area of the helmet. This is unfortunate as this is an area of the helmet where foam coverage is relatively deficient. Also, the sides and crown areas commonly are involved. In contrast, the rear of the helmet is infrequently damaged. Helmets which were recorded as having damage to their rear surfaces usually were classified as nonsurvivable. This study is not in agreement with the study of Reading et al. (1984) which indicated increased protection was required to the rear of the helmet due to the high AIS scores recorded. Almost certainly, these latter cases involved the more severe or nonsurvivable accident data.

Type of surface impacted

Table 6 demonstrates that flat, concave, and wedge shaped surfaces by far are the most common encountered during the impact sequence. The least common is the hemispherical surface. This lends weight to the argument that hemispherical surfaces should not be used in the testing of flight helmets due to their comparative rarity. However, they are associated with higher AIS scores than other surfaces.

Number of impacts sustained

The helmets studied had received from 0 - 5 separate identifiable impacts (Table 8). Fifty-eight percent of all helmets had evidence of more than one impact. If those helmets which were undamaged were excluded, then 75 percent of all damaged helmets had been involved in multiple impacts.

Type of damage sustained

This is listed in Table 7. Most obvious is the paucity of penetrating puncture damage. All such damage occurred in nonsurvivable accidents. This clearly implies the requirement for a helmet puncture test is of little relevance to the type of accident damage actually encountered in service.

Injuries sustained

The distribution of the head injuries is illustrated in Figures 12 and 13. The most common recorded type of skull fracture is basilar and these almost invariably are caused by lateral impacts to the helmet, as described by Shanahan (1985). In the present series, all basilar skull fractures, except for one, occurred in nonsurvivable impacts. The exception (AH-64) is discussed below.

A striking feature of the injury distribution is the large percentage of facial bony, and soft tissue injuries in survivable and potentially survivable accidents, which, nevertheless, resulted in fatalities. This serves to emphasize the requirement for either improved retention systems to reduce the amount of upper torso flailing and/or the provision of maxillofacial shielding to protect the facial areas from cockpit structure, or NVGs, etc.

In recent years, there has been some concern helmets and their ancillary equipment may aggravate or be the cause of neck injuries. This study does not support this contention as there were only two cases of fatal neck injuries in otherwise survivable accidents. These were due to inhalation (not strictly a neck injury) and a crush injury which was unrelated to rotational forces.

Causes of fatalities in survivable and potentially survivable accidents

Despite some of the problems associated with the SPH-4 helmet, such as poor stability and retention, which are discussed later, there were few cases where fatalities occurred in otherwise survivable or potentially survivable accidents. These cases are recorded in Table 12, which also gives some indication of possible solutions.

Integrated helmet and display sighting system

The introduction of the Apache (AH-64) attack helicopter to the U.S. Army helicopter fleet has led to the introduction of new technologies which are a foretaste of the types of equipment which we can expect to become commonplace in future years. One of the unique features of the AH-64 is the integrated helmet and display sighting system (IHADSS) which provide the aircrew with a helmet mounted display (HMD) system. This HMD provides heads-up display for flight control, navigation, night vision imaging, and weapons control. The salient features of the IHADSS are shown in Figure 19. The helmet is obviously a compromise between that which is desirable for the HMD and those features normally considered important in providing a maximum of impact protection.

Figure 20 portrays the large increase in helmet volume, which has been the result of trying to optimize the performance of the visor in relation to the HMD unit. A recent accident investigated by USAARL demonstrated a blow to this visor cover could transmit the impact energy directly to a portion of the helmet, where there is no energy absorbing liner. The compressive force was estimated to be in the region of 1000 lbs. There is little doubt that the increased profile and strike range of this helmet were the cause of the injuries sustained in this case.

Figure 21 shows the impact point of the helmet in this accident based on accident investigation carried out by USAARL personnel. An alternative approach (discussed later) to prevent this type of accident would be to improve the restraint system design, in particular the inertia reel setting.

Table 12

Causes of fatalities in survivable and potentially survivable accidents

Cause of fatality	Type of aircraft	No. of cases	Remedy
Massive facial/head trauma due to TSU strike	AH-1	2	1. Improved restraint 2. Maxillo-facial shielding 3. IBAHRS
1. Fracture of both earcups 2. Failure of retention system 3. Inadequate foam liner (3/8 in)	AH-1	1	1. Energy absorbing earcups 2. Improved retention system 3. Increased foam (already incorporated)
Basal skull fracture due to visor strike	AH-64	1	1. Improved restraint 2. Decreased helmet profile
1. Fractured earcup 2. Failure of suspension system	UH-60	1	1. Energy absorbing earcups 2. Improved retention system
1. Helmet loss 2. Severe lateral impact	UH-60	1	1. Energy absorbing earcups 2. Improved retention system
1. Helmet loss 2. Lateral impact	OH-58	1	1. Improved retention system 2. Energy absorbing earcups
1. Lateral impact	UH-1	1	1. Energy absorbing earcups
1. Helmet loss 2. Lateral impact	UH-1	1	1. Energy absorbing earcups 2. Improved retention system

Figure 19. The IHADSS helmet.

Figure 20. The large increase in potential strike envelope produced by the IHADSS helmet.

Figure 21. Apparent minor damage on the IHADSS visor cover which resulted in a fatal head injury.

Injuries caused by impact with the telescopic sighting unit (TSU) in the AH-1 Cobra

There were a number of injuries involving the (TSU) in the AH-1 Cobra. This unit, when used in conjunction with the helmet sight assembly, is used to control the TOW missile system fitted to the aircraft. During the course of this study, 23 helmets were recovered from AH-1 accidents and, in seven (30 percent) of these cases, the TSU was recorded as having caused facial injuries. Six of these cases were survivable, or partly survivable, and impact forces caused the gunner's body to flail forward and impact with the TSU. In two instances, there were fatal head and face injuries in the absence of any significant helmet damage. In order to prevent such injuries occurring, the gunner must be prevented from flailing forward, the TSU must be delethalized, or there must be the provision of maxillo-facial protection.

The latter course, although simple, has poor support from aircrew due to the addition of protective equipment to the facial portions of their helmets and the inevitable accompanying increase in discomfort and visual problems. Although the inflatable body and head restraint system (IBAHRS) would be an ideal solution, this is expensive and has its own problems. An alternative and much cheaper solution would be to employ a new and improved inertia reel system which would prevent excessive reeling out of the restraint system during the initial stages of the impact.

Current inertia reels are designed to lock at an acceleration level which exceeds 2-3 G, and it is likely this setting may allow excessive reeling out to occur prior to locking of the system. To this must be added the inherent stretch present in the restraint system under an impact load. In the near future, a limited trial is to be carried out of an inertia reel set to activate at a setting of between 1.2 G and 1.8 G. This should serve to improve the situation for the Cobra gunner, but would not eliminate the problem as impact could occur with the harness unlocked and the occupant leaning forward.

A further problem peculiar to this helmet is the presence of the pin collars (Figure 22) which fasten the HMD unit to the helmet. These attachment screws should be designed to be flush with the surface of the helmet in order to avoid snagging, possible rotational injury, or even loss of the helmet with a glancing blow. Two of the AH-1 helmets in this study demonstrated the occurrence of this type of impact, although it could not be ascertained if the rotational forces experienced contributed to the degree of injury sustained. The desirability of achieving a clean helmet surface is manifest.

Improved features

Analysis of the available data indicates that attention to the following areas would have a marked effect on the degree of head injury sustained. Totally nonsurvivable cases with massive helmet damage have been excluded from this analysis, although it does include data obtained from other nonsurvivable accidents where it was felt improved helmet design would have ameliorated the head injuries sustained. These features are identified in Table 13. Some helmets had more than one failure and all have been included in the data.

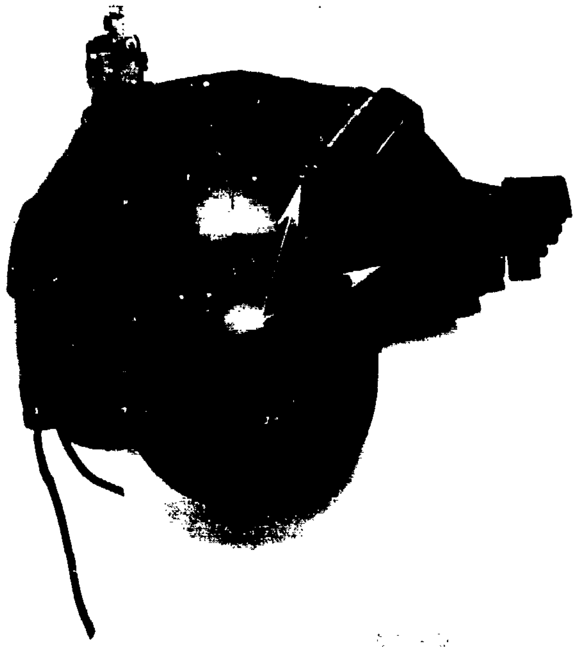

Figure 22. Cobra helmet demonstrating protruding pin collars.

The sides of the SPH-4 helmet continue to feature as the most common site for the major impact and confirms the findings of previous reports (Haley et al., 1983; Reading et al., 1984; Slobodonik and Nelson, 1977; Slobodnik, 1980). The lack of foam in this area (as shown in Figures 2 and 3) and the presence of the extremely rigid earcup are responsible for these severe injuries. The size of the earcups, which is dictated by the requirement for low frequency noise protection, also decides the shape of the SPH-4 helmet giving it its distinctive shape. An ideal helmet would have smoothly contoured sides and, hence, less volume and surface area available for impact. In the future, the emergence of technology, such as active noise reduction, should enable significant reductions in the size of the earcups to take place. The current rigid-plastic earcup doesn't yield on impact. Unpublished studies

Table 13

Major features identified as problem areas in the helmets studied

Factor	No. of times identified
Energy-absorbing earcups	39
Improved retention system	20
Improved chinstrap fastener	12
Increased energy absorption in liner	12
Improved harness restraint system	9
Maxillo-facial shielding	8
Better helmet fitting	2
Decreased helmet signature (IHADSS)	1
Strengthened peripheral areas	2

performed at USAARL have shown that the dynamic load required to fracture the standard earcups varies from approximately 750 lbs to crack the inner flange to over 5000 lbs to fracture the main body. Tolerance of humans to fracture in the tempero-parietal area is recorded as being as low as 400 lbs (Schneider and Nahum, 1972). A "crushable" earcup which would absorb energy during impact has been developed by USAARL under United States Army Contract DABT 01-79C-0250-1. The design is based on the requirement that the acoustical protection should equal or exceed that of the existing earcup and the crushing characteristics of the earcup should provide enhanced impact protection to the wearer's head. One such prototype earcup constructed of convoluted aluminum is shown in Figure 23. The specifications for the planned replacement helmet for the SPH-4, the Head Gear Unit No. 56 (HGU-56), requires the inclusion of an energy-absorbing "crushable" earcup. The reduction of force achieved by this method is a definite improvement and would surely contribute to injury reduction as indicated by Haley et al. (1983).

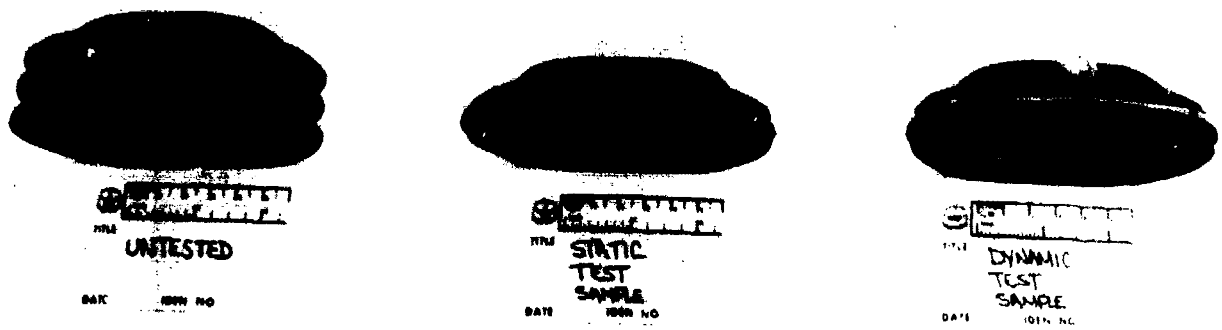

Figure 23. Convoluted aluminum earcups before and after static and dynamic testing.

Helmet loss, retention, and stability

The Reading et al. report (1984) reveals 43 (20.6 percent) of all helmets came off the wearer's head during the crash sequence. Twenty-seven (62.7 percent) were due to chinstrap failure (single variety) and 16 (37 percent) were caused by failure or excessive stretching of the retention system. Helmet retention in accidents still remains a problem with 18 (12.3 percent) being lost altogether and 26 (17.8 percent) recorded as having rotated during the impact sequence. Helmet rotation almost certainly is an underestimation as it is not easy to ascertain if it occurred during the accident unless there are telltale injuries, or the wearer is able to communicate this to the investigators. It is difficult to assess whether a chinstrap has failed unless there is obvious damage or the fact is accurately recorded at the time. Unpublished tests at USAARL have demonstrated failure can occur without any obvious damage to the snap fasteners. The chinstraps in this study all were of the improved double snap variety which have not eliminated the problem as stated in a previous report (Reading et al., 1984).

Helmet retention

As already mentioned, there were 18 cases of helmet loss in this study and a further 7 cases where the circumstances of the accident made it impossible to ascertain definitely whether helmets had indeed been lost. The causes of these helmet losses are as follows:

Chinstrap failure occurred on 11 occasions

Nine of these were due to snap failures and two to failure of the bolt retention system. One of the latter was recorded as being due to rotting of the cloth retention system. It had been hoped the introduction of the improved double snap type harness would have eliminated the problem of strap failure. The current study emphasizes the inadequacy of dot fasteners for aircrew helmets. Other types of fasteners are available and in service throughout the world. These now are being assessed for use in U.S. Army aviator helmets and their introduction would eliminate this long standing, well known, but seemingly perennial problem. Figure 24 illustrates a case of severe deformation of a dot fastener which failed in a survivable accident. An argument often advanced in favor of dot fasteners is their ease in use when donning or doffing a helmet. This is disputed as alternative fasteners are, in the authors' opinions, easier to use, and there seems to be no reason for quick release of a helmet subsequent to an accident. Indeed, all the evidence indicates that the helmet should be kept on until well clear of the crashed aircraft, refuting the argument that quick release is required.

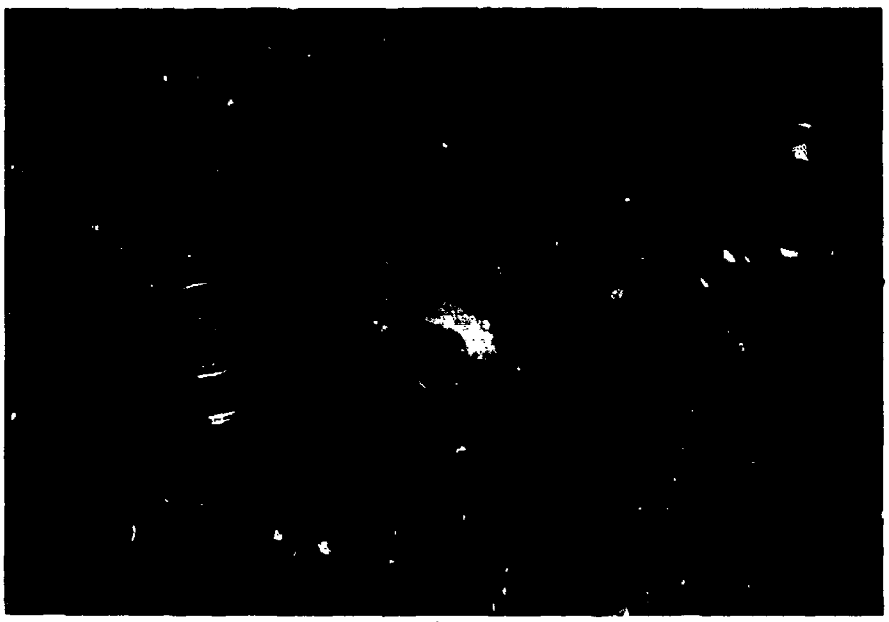

Figure 24. Failure of a dot fastener in a survivable accident.

Helmet suspension system failure

There were 20 recorded cases of helmet retention system failure.

a. Failure of the suspension tabs--14. See Figure 25.

b. Earcup detached from cloth retention assembly--4.

c. Failure of the napestrap--1.

d. Incorrect fitting of the helmet--1.

Since the primary function of an aviator's helmet remains protection, then it is essential the helmet should remain on the head during the impact sequence. Further, it should, as far as possible, remain in a stable position during the impact sequence. The frequency of multiple impacts during the present study lends further strength to this argument.

Clearly, the main drawback of the SPH-4 is its reliance on a retention system where the chinstrap attaches directly to the cloth suspension system which houses the earcup assembly. This allows excessive stretching to occur during an impact loading and largely accounts for the poor performance of the SPH-4 under simulated and real impact conditions. The suspension system retention tabs are of inadequate strength and have failed in survivable accident conditions. An SPH-4 from a recent survivable accident exhibited failure of all four retention tabs. The subsequent helmet loss resulted in the pilot receiving major head injuries with loss of consciousness--a totally unacceptable outcome. A brief check of suspension systems at USAARL revealed though some were of adequate strength, others were easy to tear apart. Quality control of stitching obviously is important, and as such components often are assembled by the lowest bidder, variation in their attributes is to be expected. Anecdotal evidence from the aviation community indicate the wearing of NVGs under normal operating conditions causes the helmet to shift on the head, thereby altering the optical axis of the system. This necessitates the aviator having to manually recenter the equipment - obviously an undesirable and unnecessary flight task. Helmet stability has become important not only in impact situations, but also in operational conditions where the maintenance of a stable viewing platform is essential. Therefore, future helmet designs should incorporate features which facilitate this desirable result. Ideally, the chinstrap should be attached directly to the helmet shell, incorporate a new fastener system, and the nape strap should be improved to avoid forward rotation of the helmet.

Figure 25. Failure of suspension retention tab stitching.

Recent studies at USAARL (Gruver and Haley, 1988) have demonstrated the poor performance of the SPH-4 and other sling suspension type helmets during simulated impact conditions. Indeed, the SPH-4 was the poorest performer of all in the standard configuration, although this was improved marginally by use of the thermoplastic liner (TPL) (Figure 26) in conjunction with a new protective styrofoam liner. The TPL consists of four layers of plastic, one layer of reticulated foam, and a removable cloth cover. It is designed to replace the standard web suspension system of the SPH-4 helmet. The methodology employed in these tests involves the use of a Department of Transportation (DOT) "humanoid" headform mounted to a DOT pendulum which is allowed to impact with a variable energy absorbing pad to control the level of deceleration. The amount of helmet movement was recorded with high speed photography.

At best, this type of test can give only an approximation of a helmet's retention capability. The headform cannot simulate the surface of the human skull with its layers of flexible tissue and covering of hair. Personal and anecdotal evidence clearly implies that the average aviator only loosely applies the chinstrap and probably will not readjust the napestrap between each sortie. In such cases, the degree of rotation and possibility of helmet loss in an accident are increased.

As already explained, part of the problem can be solved by the use of the TPL liner. However, the inherent difficulties associated with the elongation of the chinstrap and nape-ear cloth assembly still remain. One possible solution has been suggested by USAARL. This involves the use of a reinforced retention assembly. This modification increases the retention capability of the SPH-4 from a load of 280 lbs - 450 lbs, reduces helmet movement under simulated impact conditions by 45%, eliminates retention tab stitching failure, and distributes the loads over a greater area (Figure 27).

Utilization of foam compression

A previous USAARL helmet report (Reading et al., 1984) had shown the crushable polystyrene foam (density 5.2 pcf) does not compress sufficiently at a low enough load and recommended a polyurethane foam (density 2.3 pcf) be employed. This was based on the finding that 30 percent of all cases with an AIS of 3 or greater had less than 20 percent foam compression. Full utilization occurred in only 15 percent of these cases.

Data from the present study is shown in Table 11. Some caution is required to interpret the data and the following points should be considered:

Figure 26. Thermoplastic liner (TPL) which is to replace the standard SPH-4 helmet suspension system.

Figure 27. Reinforced retention system which eliminates the need for snap fasteners and retention tabs.

a. Lateral impacts to the earcup areas involve areas where there is no foam protection. Frontal areas also are not fully provided for. Table 11 excludes all those cases in which the only significant impact was lateral and those cases where there was no helmet damage.

b. The data in this series, except for one case, refers to the use of 0.5-in liners.

An analysis was carried out of the damage sustained by helmets when a period of unconsciousness or amnesia was recorded in the original records. There were 25 such cases and the percentage of foam compressed ranged from 0 to 50 percent. The distribution is shown in Figure 28. This data refers to all impacts and some helmets were struck on more than one occasion. As can be seen, the majority of helmets have little or no foam compression recorded; however, when one examines the site of the major impact, the majority (90 percent) involve either earcup, frontal damage, or the facial region. These are the areas where foam is either deficient or totally lacking. These facts are illustrated in Table 14.

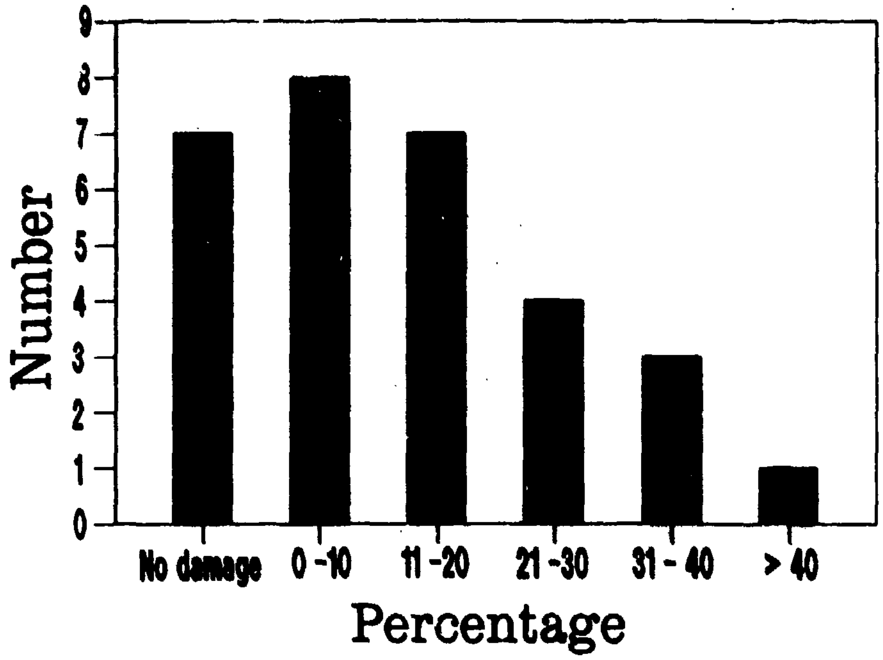

Figure 28. Percent foam compression in cases involving periods of unconsciousness or amnesia.

Table 14

Site of major impact in cases involving amnesia or unconsciousness

Site of impact	No. of cases	Percent
Frontal/viscr	9	32.14
Lateral	14	50.00
Facial	2	7.14
Elsewhere on helmet	2	7.14
No helmet damage	1	3.57

Conclusions

1. The most common sites for helmet impacts are frontal/visor (>38 percent) and lateral (30 percent). The rear of the helmet was involved infrequently and severe damage invariably was associated with nonsurvivable accidents.

2. Flat, concave, and wedge-shaped surfaces are the most likely impactors responsible for helmet damage in U.S. Army rotary-wing aircraft accidents.

3. Abrasion, delamination, and fracture were the most frequently recorded type of helmet damage. Punctures were rare and associated with nonsurvivable accidents.

4. Helmet standards which require the use of hemispherical impact surfaces and puncture resistance testing are unrealistic and bear no relation to the type of helmet damage actually observed in practice.

5. Earcup damage continues to be a major problem and basilar skull fractures correspondingly were the most common single type of skull fracture sustained.

6. Facial bony and soft tissue injury are frequent and are often the result of upper torso flailing due to inadequate restraint and/or high G setting of the inertia reels used. Cervical neck injuries were uncommon and in survivable accidents usually were minimal.

7. The increased signature of the AH-64 IHADSS helmet is an undesirable feature and should be avoided in future helmet design.

8. The frequency of facial impact with the TSU in the AH-1 Cobra is cause for real concern. The visor cover pin collars also are a totally unnecessary protrusion.

9. The requirement for good low frequency sound protection has led to the use of large rigid earcups which transmit the force of impact directly to the skull. From the data in this report, lateral impacts were responsible for a large proportion of fatal and lesser injuries.

10. Helmet loss, rotation, and stability remain a major problem. The factors mainly responsible are:

a. The improved dot fasteners continue to fail in survivable accidents.

b. The retention tab system is of inadequate and variable strength.

c. The napestrap does not appear to prevent the forward rotation of the helmet during the impact sequence.

d. There is concern about the quality of helmet fit obtained in the field, as opposed to laboratory conditions.

e. The design of the retention system allows excessive stretch to occur during impact loads. This facilitates helmet rotation and possible helmet loss.

f. Foam liner protection is inadequate in the frontal and lateral areas, where most impacts occur. Over 90 percent of all cases of amnesia or unconsciousness were subsequent to frontal, lateral, or facial impacts.

g. Most of the problems with the SPH-4 helmet, alluded to above, were first identified in the APH-5 helmet in 1962.

Recommendations

1. Military standards for aviator helmet protection should employ a flat impacting surface and discard the requirement for a penetration test.

2. The military standard for helmet impact (MIL-H-43925) should be rewritten to reflect the technology now available and the results achievable.

3. The introduction of energy-absorbing earcups should be expedited. It is over a quarter of a century since this problem was first identified and aviators continue to die and suffer injuries as a result.

4. Future helmets should be designed with as smooth a surface and small a volume as practical.

5. Research urgently is required to solve the problem of facial injuries in the AH-1 Cobra.

6. Dot type fasteners on the chinstrap continue to fail and should be replaced as soon as possible.

7. Suspension system attachment tabs need immediate strengthening to avoid failure in survivable and potentially survivable accidents.

8. Suspension and retention systems in future U.S. Army aviator helmets should not be based on the present design. A much more stable system is required.

9. There should be a military standard for helmet retention and stability.

10. Future helmet designs should, as a minimum, incorporate extra protection in the frontal and lateral areas.

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Appendix A

ALSERP helmet review form

1. USAARL case number
2. USASC case number
3. Aircraft type
4. Last name of wearer
5. SSN
6. Wearer's age
7. Helmet type
8. Helmet manufacturer
9. Helmet contract number
10. Position of wearer at impact
11. Seat orientation
12. Was accident fatal to wearer?
13. Were head, neck, or face injuries present?
14. Did death occur as a result of these injuries?
15. Could an improved helmet have lessened the severity of the impact?
16. Was the wearer rendered unconscious?
17. What was the period of time involved?
18. Was there any amnesia?
19. What was the period of time involved in days/hours/minutes?
20. What feature of improvement could have lessened the severity of the impact?

List head, neck and face injuries below as coded by USASC:

21. List injuries 1

22. List injuries 2

23. List injuries 3

24. List injuries 4

25. List injuries 5

26. List injuries 6

27. List injuries 7

28. List injuries 8

29. List injuries 9

30. AIS old

31. AIS 1980

32. Did the helmet come off the wearer's head?

33. Chinstrap failure?

34. If yes, specify type of failure.

35. Retention system attachment point failure?

36. If yes, specify type of failure.

37. Earcup damage?

38. If yes, specify which earcup.

39. If yes, specify earcup damage.

40. Visor position at impact?

41. Was visor or visor cover broken?

42. If yes, specify damage to the visor or cover.

43. List injuries caused by broken visor 1.

44. List injuries caused by broken visor 2.

45. List injuries caused by broken visor 3.

46. List injuries caused by broken visor 4.

47. Did the helmet rotate and expose head to injuries?

Clip damage looking down into helmet

1 = No deformation.

2 = Slight deformation [<2mm]

3 = Moderate deformation [>2mm <6mm]

4 = Severe deformation [>6mm]

48. Clip damage left front =

49. Clip damage front =

50. Clip damage right front =

51. Clip damage right rear =

52. Clip damage right =

53. Clip damage left rear =

54. Helmet disposal

Impact surface information

55. Impact surface 1

56. Impact surface 2

57. Impact surface 3

58. Impact surface 4

59. Impact surface 5

60. If details concering the nature of the object struck are known, insert them here.

61. Enter notes concerning impact location.

Insert below type of helmet damage by region

62. Crown front

63. Crown left side

64. Crown right side

65. Crown rear

66. Front left

67. Front right

68. Left side front

69. Left side rear

70. Right side front

71. Right side rear

72. Rear left

73. Rear right

74. Permanent foam compression based on a thickness of ____________ (taken from database).

Insert below percentage compression and area involved

75. Impact 1

76. Impact 2

77. Impact 3

78. Impact 4

79. Impact 5

80. Is it possible to correlate impact damage with the degree of head injury present?

81. Is simulation of the impact damage possible?

82. Any comments and add your opinion as to whether the helmet contributed to saving the wearer's life or reducing the injuries.

83. Starred items for attention

84. Survivability of the accident

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