The Cost-Effectiveness of Air Medical Helicopter Crash Survival Enhancements

An Evaluation of the Costs, Benefits and Effectiveness of Injury Prevention Interventions

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Key Words: air medical, cost-effectiveness, crash survival, crashworthiness, emergency medical services (EMS), energy-absorbing seats (EAS), head injury, helicopter, helmet, injury, intervention, medical crew, Nomex, pilots, prevention, seating systems, spinal injury, thermal injury

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Abstract

Objective: This study evaluates EMS helicopter-injury reduction interventions and associated costs for survivable crashes. Specific injury categories evaluated include head injuries, spinal injuries and thermal injuries. The benefits and costs of the preventive interventions are evaluated through cost-effectiveness analyses that provide a basis for informed safety-enhancement decisions for EMS helicopter operators, based on the most cost-efficient interventions.

Methods: The incidence and type of injuries experienced by EMS helicopter occupants were determined, and future risk of injury was estimated. Then the costs of those injuries, as well as the costs of the preventive interventions, were determined so estimates could be made of the cost benefits of the injuries prevented. Estimates were made regarding current levels of injury prevention interventions already in the field and their effectiveness in preventing injury.

Results: Improvements can be made to reduce the risk of injury to medical crew and pilots in survivable crashes. Nomex uniforms, helmets, and energy-absorbing seats (EAS) for medical crew members all prove cost-effective in reducing preventable injuries in survivable crashes.

Conclusion: Emergency medical service shelicopter occupants should wear fire-resistant uniforms and helmets, and medical crew members should have EAS systems when available. These EAS systems also are recommended for pilots, although they were not shown to be cost-effective based on the projections developed in this study.

Introduction

The aviation system in the United States is among the safest in the world. Aviation crashes are truly rare events, and when they do occur, most—including those involving air medical aircraft—involve some aspect of human performance failure. Yet, while crashes are rare, their occurrence often generates a disproportionate interest among the media and public. This attention can be particularly intense when the involved aircraft is used in air medical transport.

As crashes have become fewer, effective interventions to improve aviation safety have become more difficult to identify. Increasingly competitive environments make application of safety interventions difficult since safety benefits can be difficult to quantify. Thus, the decision on how to distribute rare safety resources should be based on knowledge of which interventions are most effective.

Most aviation safety efforts focus on prevention of the crash and place little emphasis on mitigation of injuries in survivable crashes. Emergency medical services helicopters, however, are at higher risk of crashing than helicopters used in other types of transport, and EMS helicopter occupants are far more likely to be injured in these crashes.[1] The focus of this study is to evaluate EMS helicopter-injury reduction interventions and their associated costs, identifying specific injury categories and preventive interventions. The benefits and costs of the interventions are evaluated through cost-effectiveness analyses that provide a basis for informed safety-enhancement decisions for EMS helicopter operators based on the most cost-efficient interventions.

Background: Past Research

While efforts to reduce injuries and death in aviation crashes historically have focused on crash prevention, significant research has also been conducted on crashworthiness and occupant survival.[a] In a comprehensive overview of human impact tolerance, Snyder states that there are more than 6,000 references in the literature relating human tolerance to abrupt acceleration.[2]

Most helicopter crashworthiness and survival research has been conducted by or for the U.S. Army during the past 30 years and has included a combination of experimental and observational approaches; little research has been conducted in the civilian sector. By the late 1970s, for example, the U.S. Army had completed more than 40 full-scale crash tests of instrumented helicopters in an attempt to gather information on crash dynamics in the helicopter environment. The cumulative findings from this research were compiled in a seminal five-volume design guide for U.S. Army aircraft to improve crash survival.[3] Topics covered include aircraft design criteria for crashworthiness, the crash environment and human tolerance, aircraft structural crashworthiness, seats and restraint systems, and post-crash fire reduction/elimination. The U.S. Army crashworthiness program has proven highly successful: All new U.S. Army helicopters incorporate crashworthy features as part of their design.

Human Tolerance and Crashworthiness

The National Transportation Safety Board (NTSB) notes that approximately 80% of civilian helicopter crashes occur at relatively low speeds.[4] It is reasonable to assume that many of these crashes are survivable.[b]

Table 1 displays the acceleration tolerance of properly restrained healthy adult young males (mean age 26), which results in little or no injury to the individual. The acceleration forces are applied for 0.100 second.[c]

Table 1

Human Whole Body Tolerance to Impact[3]

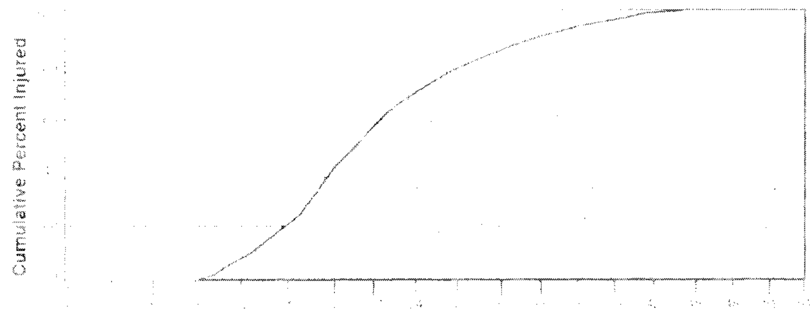
ACCELERATION DIRECTION (vernacular description)	AXIS	G-LOADING
Chest to Back (head-on collision	-Gx	25-45
Back to Chest (hit from behind)	+Gx	45-83
Headward (hard landing)	+Gz	15
Tailward (negative g)	-Gz	15
Right or Left (hit from either side)	+ or -Gy	20

Figure 1

Vertical Velocity Change and Spinal Injury

Cumulative Spinal Injuries Among Military Aviators

OH-58 (Bell 206 A/B)



A study on civilian helicopter crashworthiness conducted in 1985 by Coltman noted that the most common injuries to occupants in survivable crashes were head injuries (32%), spinal injuries (16%), neck injuries (12%) and torso-related injuries (12%).[5] The authors concluded that the vertical-impact scenario was the most preventable hazard for occupants and recommended the incorporation of vertical-energy absorption to reduce the risk of injury in survivable crashes for properly restrained occupants.

Spinal Injury

Spinal injury among helicopter occupants is not an uncommon occurrence in even minor crash landings. Shanahan conducted an evaluation of spinal injury among U.S. Army aviators and found that 22% of the occupants in survivable crashes in an OH-58 helicopter (similar to a Bell 206) experienced some type of spinal injury. He further concluded that 80% of the spinal injuries in this group occurred at vertical-impact velocities of less than 30 feet per second (fps) (roughly 20 mph).[6] This finding is represented in Figure 1.

As can be seen, the incidence of spinal injury begins to increase at approximately 9 fps vertical-velocity change. This increase in spinal injury is strongly correlated with the failure of the skid landing gear of the OH-58. The correlation between vertical-velocity change and type of injury (sprain, fracture/dislocation or multiple spinal injury) also is associated with increased velocity changes, although not as strongly. Shanahan speculates that the lack of a strong dose-effect relationship between injury severity and velocity change may be due to natural biological variation of the occupants or other factors not accounted for in his statistical modeling.

Turnbow, another U.S. Army researcher, conducted many actual crash tests with small U.S. Army helicopters to measure crash loadings in the cabin. For example, an OH-4A was dropped from a tower to simulate a purely vertical crash-impact scenario of 25 fps. Researchers found that the passenger floor experienced 40g of acceleration, and the anthropometric dummy in the passenger seat experienced 69g of acceleration in a standard non-crashworthy seat.[7]

FAA design criterion for currently manufactured helicopters require that occupants be protected in crash conditions with vertical-velocity changes of 5 fps (roughly 3.4 mph).[d] This protection is normally designed into the landing gear and not the seat structures.[e] It is interesting to note that both Shanahan and Coltman found greatly increased risk of spinal injury at vertical-velocity changes slightly above the FAA requirement. This finding suggests that spinal injury risk increases dramatically with the failure of the landing gear. The seat and fuselage in most of the current helicopters provide little additional protection above the 5 fps requirement. Both Shanahan and Coltman recommend that crash protection be improved in the vertical plane to approximately 30 fps (Coltman, 26 fps; Shanahan, 30 fps), concluding that current technology makes improving helicopter crashworthiness feasible. Shanahan further states that retrofitting EAS in the OH-58 is probably the most economical and technically feasible method to provide protection for the occupants for 30 fps vertical impacts.

The actual injury mechanism of spinal injury among helicopter occupants involves a combination of compression loading and spinal flexation as an occupant "jack-knifes" forward or sideward. Typical spinal injuries include sprains and strains, compression fractures or dislocations, as well as more serious injuries including trauma to the spinal cord itself. Most of these injuries occur to the lumbar and thoracic spine, while injuries involving the cervical spine are far less common.

Coltman describes the compression loading failure as follows:

> Before damage occurs there is a slight increase in disc volume, bulging of the disc, and deflection of the bony end plates and vertebral body. As the compressive load increases, fluid is forced from the disc into the vertebral centrum, and in turn, out of the vertebral centrum through small vascular foramen (openings) on its surface. The bony end plates, with underlying trabecular bone, also fracture and yield. . . . Further, since the center of gravity of both the head and torso lies anterior to the spine, their weight creates a bending movement within the spine. . . . the leverage that external loads exert on the spine (head, torso) is often quite impressive.[8]

While incorporation of improved crash protection in the vertical plane does not guarantee an elimination of spinal injuries, it does result in a significant improvement. United States Army experience with a 14.5g protection for its aviators indicates only 4% to 5% of those in survivable crashes experience any form of spinal injury. This is a marked improvement over the 20% to 30% rate experienced with earlier aircraft.[8]

Table 2

Head Injury Distribution Among Military Aviators

Head Injury Severity and Cause of Death

	Unhelmeted Sample (n=104)		Helmeted Sample (n=1,383)	
Head Injuries	**Number**	**Percentage**	**Number**	**Percentage**
Severe	17	16.3	60	4.4
Fatal	8	7.7	17	1.2
Total	25	24.0	77	5.6

Head Injury and Helmets

According to Coltman's research, head injury is the most common injury among civilian helicopter occupants. Yet little research has been done on the effectiveness of helmets in reducing head injury among this group.[5] United States Army aviators, however, typically wear helmets and provide a population that can be evaluated for helmet effectiveness in reducing injury.

Crowley, a U.S. Army physician, evaluated the effectiveness of helmets in preventing head injury among military occupants in survivable helicopter crashes.[9] He found that those without helmets were almost four times as likely to suffer serious head injury as those with helmets (relative risk = 3.8, 95% confidence interval [CI] = 2.0–7.2), and more than six times as likely to experience fatal head injuries as those without helmets (relative risk = 6.3, 95% CI = 2.2–18.2). Comparison of occupants limited to the main cabin showed unhelmeted occupants were at five times the risk (relative risk = 5.3, 95% CI = 1.5–11.5) as those with helmets for serious head injury, and 7.5 times the risk (relative risk = 7.5, 95% CI = 1.2–47.5) for fatal head injuries. The study was based solely on military data and did not consider differences in helicopter types and crash severity. Table 2 provides the injury severity distribution among those with and without helmets.

Crowley concludes that helmets offer an increased level of head protection for military helicopter occupants involved in survivable crashes. The study's external validity and applicability to EMS helicopter occupants, however, often has been questioned by civilian operators. There is little doubt that military occupants are different from EMS helicopter occupants in age and sex distributions, aircraft type and crash scenarios. While Crowley acknowledges these differences, he concludes that a large difference between injury outcome for helmeted and unhelmeted occupants in this study is not due solely to characteristics unique to military aviation and that the findings are applicable to survivable EMS crashes with similar crash profiles as those in the study.

Reading evaluated the performance of the SPH-4 helmet among two groups of U.S. Army aviators: one group who lost their helmets during the crash sequence and a comparison group whose helmets remained on their heads.[10] In all of these

Figure 2

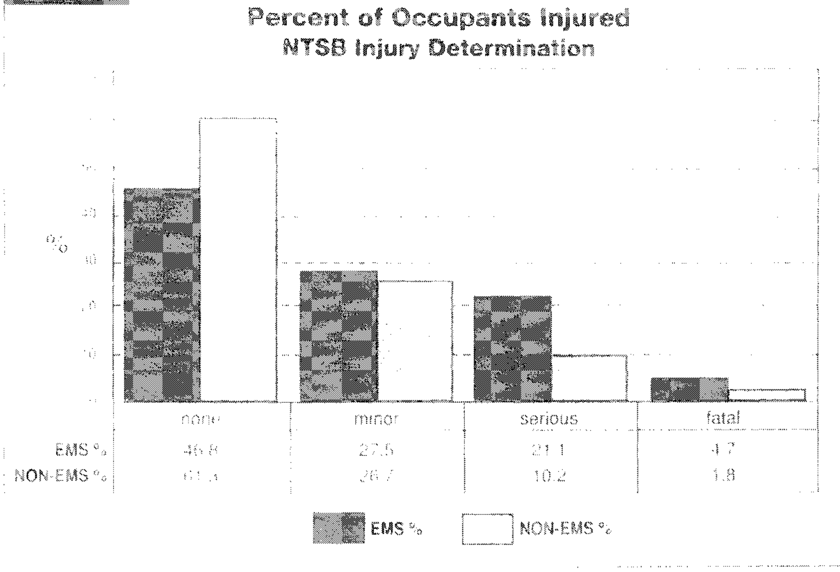
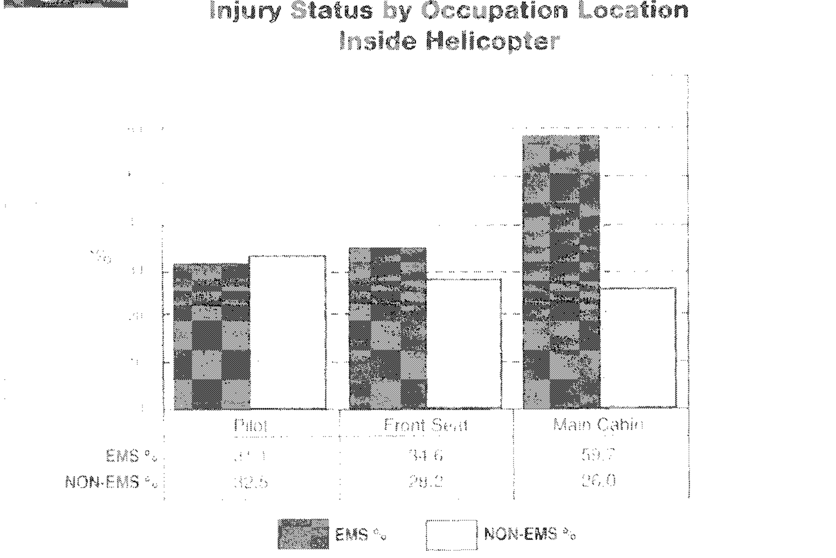


Figure 3



cases, some damage to the helmet indicated a head strike for the wearer. Reading found that 24% of those who retained their helmet received no head injury as opposed to only 5% when the helmet was lost, almost a fivefold difference. Of those who retained their helmets, 25% received severe head injury, compared with 67% for the helmet-lost group, approximately a two-and-a-half-fold difference. Twenty-eight percent of the injuries occurred to the front of the head, 5% to the rear and 32% to the side. Side impacts caused the most severe injuries.

Multiple studies have evaluated the effectiveness of motorcycle helmets in preventing injury. Many of these studies are limited because they do not control for the effect of multiple injuries on the outcome of the rider, or they focus only on death. Shankar conducted a study that evaluated helmet use and its relationship to injuries that also controlled for multiple injuries.[11] The study found that 27% of those motorcycle drivers who were without helmets and were involved in crashes received a head injury compared with 11.5% of those who wore helmets, a twofold difference.

Post-Crash Fire and Burns

Burn injuries occur in approximately 20% of the civilian helicopter crashes with known injuries. In another 25% of crashes, fuel often leaks close to the occupants without igniting.[5] Knapp, an U. S. Army researcher who conducts fire safety research, describes the helicopter post-crash fire as follows:

> Helicopter crashes have a high vertical acceleration component that crushes fuel cells located beneath the cockpit and passenger compartments. Misting of the fuel in the cockpit is common. Rotor action causes the aircraft to roll over or beat itself apart structurally. Fire is immediate and rapid spreading. Small internal volumes surrounded by large areas of plexiglass that usually break open on impact dictate a maximum time to egress and be outside the fireball of 17 seconds. Cause of death is flame contact and super heated air or flame inhalation.[12]

Knapp and his colleagues evaluated U.S. Army helicopter crashes and the risk of fire for the period of 1968–1976. They found that post-crash fire occurred in 13% of the survivable helicopter crashes among helicopters without crashworthy fuel systems.[f] The crashes were classified according to survivability and whether the aircraft was equipped with a crashworthy fuel system. Army crash data compiled by the U.S. Army Agency for Aviation Safety were reviewed for 1970–1976. The helicopters involved in crashes were limited to those without crashworthy fuel system designs. The crashes evaluated in the second period included only helicopters with crashworthy fuel systems.

Knapp found that in survivable crashes where the helicopter was not equipped with a crashworthy fuel system, 37% (95 of 254) of all fatalities and 5% of all injuries (64 of 1,361) were due to post-crash fire. In survivable crashes where the helicopter was equipped with crashworthy fuel systems, there were no fatalities due to post-crash fire (out of 44 total), and only 1.3% of the injuries were due to fire (5 of 391). Clearly, the addition of crashworthy fuel components to U.S. Army helicopters has proven highly successful in reducing thermal injuries.

Among civilian EMS helicopter operators, the only fire protection normally used is Nomex aramid fire-resistant flight clothing. In a literature review, no citations were found referencing the effectiveness of Nomex in preventing thermal injury or death in survivable crashes among civilian helicopter occupants. However, it is known that fire-resistant clothing will reduce the risk of thermal injury up to four times that of normal clothing.[13] And a study conducted by Krasny evaluating firefighter protective clothing suggests firefighters have approximately 10 seconds to escape when a flashover occurs.[14] A flashover fire generates temperatures close to that of a fully developed post-crash fire, which can reach 2,000° F within 20 seconds of the crash impact.[15]

Clearly, fire-protective clothing will not protect a survivor of a helicopter crash long when subjected to an intense post-crash fire. Fire intensity, size, propagation rate and the survivor's post-crash injuries all will influence the survivor's ability to escape the fire. The main advantage of fire-protective clothing appears to be providing added seconds to escape the fire and minimizing thermal injuries from radiant heat and the combustion of flammable clothing.

Table 3

Severe Burn Injury Cost Extimates

Author	Cost	Population	Severity Index	1994 Cost
Lofts JA[16]	Direct	Burn patients admitted to hospital	30+% body surface burned	$54,360
Knapp SC[12]	Direct and morbidity	U.S. Army aviators injured in helicopter crashes	Thermal fatality, Thermal injury	$275,000 $26,700
Miller TR[17]	Direct and morbidity	National sample of automobile occupants with burn injury	MAIS 4* MAIS 5	$171,696 $1,551,584

* *Maximum abbreviated injury scale*

Table 4

Spinal Injury Cost Estimates

Author	Cost	Population	Severity Index	1994 Cost
Shanahan DF[6]	Direct and morbidity	Army aviators in light army helicopter survivable crashes	Sprain/strain Fracture/dislocation Multiple/extreme	$9,425 $122,053 $567,600
Miller TR[17]	Direct and morbidity	National sample of automobile occupants with spinal cord injury	Complete quadriplegia Complete paraplegia Incomplete paraplegia	$700,000 $500,000 $300,000
Miller TR[18]	Direct	National sample of automobile occupants with spinal cord injury	MAIS 3* MAIS 4 MAIS 5	$17,743 $240,431 $311,887
Berkowitz M[19]	Direct	Nationwide survey of traumatic spinal cord injury	Mean cost per injury	$109,000

* *Maximum abbreviated injury scale*

Table 5

Head Injury Cost Estimates

Author	Cost	Population	Severity Index	1994 Cost
Bennet BR[20]	Direct	Sample of traumatic brain-injured patients	Mean value of all severity	$15,187
Pennings JL[21]	Direct	Sample of severe blunt brain injury	Mean value for positive outcome among young	$163,532
Shankar BS[11]	Direct	Motorcycle drivers with no helmets in Maryland	Mean value of all	$37,653
Miller TR[18]	Direct	National sample of automobile occupants	MAIS 1* MAIS 2 MAIS 3 MAIS 4 MAIS 5	$4,684 $6,503 $14,954 $61,876 $215,457
Miller TR[17]	Direct and morbidity	National sample of automobile occupants	Average disabling MAIS 5 MAIS 4	$1,565,000 $378,208 $176,062
Kraus JF[22]	Direct	Sample of San Diego, Calif., residents with mild injury	Concussion Other intracranial	$3,251 $5,140

* *Maximum abbreviated injury scale value*

EMS Helicopter Occupant Crash Survival

A study completed in 1992 by this author evaluated the injury experience of EMS helicopter occupants involved in survivable crashes. This study compared the crash and injury experience of EMS helicopter occupants with that of similar non-EMS helicopter occupants during a 10-year period.[1] It was discovered that EMS helicopter occupants are at greater risk of serious injury and death compared with occupants in similar non-EMS helicopters in survivable crashes.

Figure 2 shows the distribution of injury severity for occupants of both EMS and non-EMS helicopters. Figure 3 shows injury risk stratified by occupant location within the helicopter.

Clearly, EMS occupants located in the main cabin are at greater risk for injury than any other group. While the study did not prove causation, it did show an increased risk of injury among the main-cabin occupants. This increased risk is most likely due to medical modifications to the helicopter's main-cabin area. The study also showed that EMS main-cabin occupants are three times more likely to receive serious back injuries compared with non-EMS main-cabin occupants (relative risk = 3.1, 95% CI = 1.4–7.0) and 11 times more likely to suffer serious head injuries (relative risk = 10.9, 95% CI = 1.4–84.0). Overall, EMS helicopter main-

Table 6

Energy-Absorbing Seat Effectiveness in Reducing Spinal Injury

Author	Population	Condition	Results
Coltman JW[5]	U.S. adult civil flying population	Vertical forces do not exceed 10.5 g for occupants in survivable crashes	4% to 5% spinal injury rate
Fox RG[23]	Pilots of OH-58 helicopter	50th percentile Army aviator, 26.5 fps vertical-velocity crash scenario	Protection for 90+% of survivable/ partly survivable OH-58 crashes
Shanahan DF[6]	Army occupants of OH-58 helicopter involved in crashes	Increase vertical impact protection to 30 fps	80% reduction of spinal injury in survivable crashes.

Table 7

Helmet Effectiveness

Author	Population	Condition	Results	
Reading TE[10]	Army helicopter occupants who lost helmet in crash	Helmet lost	Injured	95%
			Severe injury	67%
	(limited only to those with injuries)		Average AIS*	4.3
		Helmet retained	Injured	76%
			Severe injury	25%
			Average AIS	2.7
Crowley[9]	Army helicopter occupants with and without helmets (included all occupants)	No helmet	Severe injury	16%
			Average AIS	8%
		Helmet	Severe injury	4%
			Fatal injury	1%
Shankar BS[11]	Maryland motorcycle riders involved in crashes	Helmet	Head injury	40%
		No helmet	Head injury	20%

**Abbreviated injury scale*

cabin occupants are more than four times as likely to be killed or seriously injured in survivable crashes as compared with main-cabin occupants in non-EMS helicopters (odds ratio=4.4, 95% CI = 1.7–11.6).

The research presented here demonstrates a significantly greater risk of injury for EMS helicopter occupants than the risks already experienced by non-EMS helicopter occupants as described by Coltman.[5] This paper describes injury reduction interventions for EMS helicopters, their associated costs and their potential benefits. The evaluation is limited to head, spinal and thermal injury.

Costs of Injury

Review of the literature shows that a large amount of research has been conducted on the cost of injuries to society. This is understandable since injury remains one of the largest causes of preventable morbidity and mortality for those under 44 years of age.[24] Unfortunately, there is a large amount of variation in these cost estimates due to different methodological approaches used by the researchers and the large amount of natural biological variation among individuals in response to injuries. Tables 3, 4 and 5 present relevant findings from researchers evaluating severe burn costs, spinal injury and head injury.

The data presented in the tables are provided for the reader's information. Clearly, the nature of the study, the population chosen for study and the type of cost estimation all have a direct influence on the estimated cost for an injured individual. These references were determined to be the most relevant to the type of injuries sustained by helicopter occupants involved in survivable crashes. The values used for the cost-effectiveness calculations in this study are based on these data and are provided in the Findings section.

Intervention Effectiveness

An essential part of this analysis involved determining the effectiveness of a given intervention in preventing injury. Estimates of intervention effectiveness were derived from review of appropriate literature. No citations were found concerning the effectiveness of Nomex, or other fire-resistant fabrics, in preventing thermal injuries among helicopter occupants. Citations were found, however, concerning helmet and EAS effectiveness. These studies involved both civilian and military-only populations. These data are presented in Tables 6 and 7.

As can be seen, different methods were used by different researchers to report their findings. As with the cost of injury estimates, the values used in the cost-effectiveness analyses are reported in the Findings section.

Methods

The methods for this study included three main components. First, the incidence and type of injuries experienced by EMS helicopter occupants were determined. This information was used to estimate future risk of injury per crash. Second, the costs of those injuries, as well as the costs of the interventions, were determined so estimates could be made of the benefits of any injuries prevented. Last, estimates were made about current levels of certain injury prevention interventions already in the field and their effectiveness in preventing injury. Each of these components is discussed in greater detail below.

Crash Selection and Injury Determination

All EMS helicopter crashes that occurred between 1978 and 1992 were included in this analysis. Complete crash records were obtained from the NTSB, including both the computerized record of each crash, as well as the complete crash docket on microfiche. The records were reviewed to determine crash survivability with each crash categorized as "survivable," "partly survivable" or "nonsurvivable." Only those crashes deemed "survivable" or "partly survivable" were included in this analysis. Once all the crashes were coded, a 20% sample was randomly selected and recoded to check for intrarater reliability. The Kappa statistic was used as the measure of association since it accounts for the effects of chance agreement.[25]

Once survivability status had been determined, occupant injury and location in the cabin were determined. Injuries were coded by body region, severity and type of injury when known. Additionally, injury severity was evaluated against the NTSB indices of occupant injury severity (none, minor, serious and fatal). As with crash coding, a 20% sample of occupants was randomly selected and their injuries recoded to check for intrarater reliability. (See Endnote A for more information on crash and injury coding methodology).

Specific injury information for approximately 17% of the injured occupants was unknown, although their NTSB injury category (none, minor, serious, fatal) was known. The distribution of known occupant injury types by NTSB injury category was applied to this 17% in the final model to account for these injured individuals. Age, location, sex and other variables were compared between the injury-known and injury-unknown groups to determine if there were any significant differences between the groups. None were discovered.

Cost of Injuries and Interventions, Intervention Effectiveness

Estimated injury costs were determined following review of relevant literature—primarily that originating within the U.S. miliary. While data on estimated injury costs are extensive in the general literature, much of the information is not applicable to this study. Injury mechanisms in helicopter crashes are different than those causing injuries among automobile occupants. For example, helicopter occupant injuries, especially thermal injuries, are likely to be far more severe than those of burn victims who report to hospital emergency departments.

Injury costs are reported as direct, morbidity or mortality.[26] Direct costs typically include transport, acute care and associated rehabilitation costs. Morbidity costs include direct-care costs, as well as lost wages while injured. Mortality costs include the loss of lifetime earnings as well as the cost of the injury itself. Liability costs are not included in the estimates of injury costs, but estimated data are presented for the readers' information.

Estimated costs for selected injury prevention interventions were based on information provided by manufacturers via telephone interviews or published promotional literature. Estimates on the effectiveness of the interventions were determined through review of the relevant literature. An effectiveness coefficient was developed for each intervention in recognition that no intervention is 100% effective. These coefficients were used to reduce the value of benefits from injuries prevented and are presented in the Findings section. When intervention effectiveness could not be determined, a 50% effectiveness was assumed and is noted.

The prevalence of interventions already in the EMS helicopter fleet was determined through the application of a telephone survey to a random sample of 54 (approximately 23%) of U.S. air medical helicopter operators. Information was gathered on the number and makes of helicopters used, priorities in EMS interior design, number of staff who routinely fly, use of helmets and other protective gear, and shoulder harness availability.

Cost-Effectiveness Model and Basic Assumptions

The cost-effectiveness model applied to this analysis provides the estimated cost for each injury prevented through the application of one of the following interventions:

1) Energy-absorbing seats
2) Helmets for all occupants
3) Nomex flight suits
4) Shoulder harnesses for all occupants

Each injury is treated as an independent event, but it should be recognized that injured helicopter occupants rarely suffer just one injury. Multiple injuries have a negative effect that is greater than the sum of the injuries considered separately.[27] This multiplicative effect was not accounted for in the analysis.

Estimates were predicated on a stable fleet size of 200 helicopters a year. Each helicopter was assumed to have a useful life of 20 years, and one pilot and two medical crew members. The estimated benefits were based on a 100% compliance in the industry for each intervention. Costs did not include the costs of interventions already used by air medical programs. Useful life of each intervention was based on estimates provided by manufacturers or industry representatives. The survivable crash and injury rate experienced for the 15 years between 1978–1992 was used for future crash and injury projections.

A 6% discount rate was used to discount future costs or benefits to 1994 dollars. This rate has been chosen by many other researchers conducting injury research.[17,26,28] A 6% rate was also chosen to inflate medical costs of injury to 1994 dollars from research conducted in years past. While the Medical Consumer Price Index has averaged much higher (8% to 10%) over the past 10 years, the value for 1993 was 6%.[29] The most conservative figure was chosen. The actual model used for the cost-effectiveness calculations is based on a model presented by Teutsch to address the effectiveness of disease and injury prevention programs.[30]

As mentioned earlier, the results of the analyses are presented as the costs of each injury prevented (where negative costs are considered benefits).

Cost-Effectiveness = Net intervention cost/injuries prevented

Net intervention cost = Fleetwide cost of an injury prevention intervention—benefit of injuries prevented

Findings

Crash and Injury Distribution

Ninety EMS helicopter crashes occurred during the 15-year period of 1978-1992, an average of six per year. Of these, 64 (71%) were determined to be survivable or partly survivable, an average of 4.3 per year. There were 174 occupants onboard these aircraft, excluding patients. Sixty-four of these were pilots, and 110 were crew members. One-hundred (57%) of the pilots and medical crew received

Table 8

Occupant Injury Distribution

Major Categories of Injury Distribtuion in Survivable Crashes

Injury	Pilots		Crew	
Serious back	4	15%	22	32%
Minor back	2	7%	9	13%
Serious head	1	3%	7	10%
Minor head	0	0%	4	6%
Burns	1	3%	3	4%
Internal	1	3%	8	12%
Extremities	1	3%	10	15%
Number of known injuries	27		68	

**Serious back injuries include fractures, dislocations and spinal cord trauma. Minor back injuries include sprains and strains. Serious head injuries include concussion, fractures, subdural bleeding and other blunt trauma brain injury. Minor head injuries include lacerations and contusions. Injuries to extremities include fractures, and sprains and strains.*

Table 9

Survey Responses

Telephone Survey Responses n=54

Question	Response	Comment
Helmets provided and worn?	yes =26 (48%)	Includes "provided and worn" and "provided, wearing optional" responses
Fire-resistant uniforms?	yes =35 (65%)	Specified "fire-resistant," not Nomex
Heavy boots?	yes = 41 (76%)	Includes "provided and worn" and "not provided but normally worn" responses
Shoulder harness for medical crew positions?	yes = 48 (89%) no = 3 (6%) some = 3 (6%)	

some type of injury in these survivable crashes.

Injury distribution patterns among the pilots and crew were very different. Among those injured, 45% of medical crew members suffered some form of back injury compared with 22% of the pilots. The difference in head injury is even greater. Sixteen percent of the medical crew members injured experienced some type of head injury, while only 3% of the injured pilots experienced head injury. The number of pilots and medical crew who received thermal injuries was very low, much lower than the literature would suggest. This is discussed in more detail in the Limitations section.

Table 8 presents the injury distribution among those injured in the survivable crashes. Only the major categories of injuries are presented: Categories such as "contusions," "lacerations," "injuries unknown" and "other injuries" are not included. The injuries presented are not mutually exclusive, since an occupant can experience more than one injury. Also, these data must be viewed with caution since they represent known injuries only—information on type of injuries is not available in many NTSB crash reports although the occupants are injured. This limitation and other concerns are discussed in more detail in the section dealing with study limitations.

Survey Findings

The results from the telephone survey of a sample of helicopter medical programs are presented in Table 9. The main purpose of the survey was to develop a baseline measurement of the number of programs currently using flight helmets and fire-resistant uniforms. These data then were used to determine the fleetwide cost of equipping those not using this equipment.

As can be seen, helmet usage is approaching 50% of those flying air medical helicopters. Fire-resistant uniform use is even greater at 65%. The majority of helicopters have shoulder harnesses for the medical crew (shoulder harnesses are required for the pilots by the FAA), but a small number still need to be equipped.

Fire-Resistant Uniform Cost-Effectiveness

For this analysis, the average number of crew members who routinely fly was set at 18 for single-helicopter programs. This value was predicated on responses to the telephone survey, which indicated that, on average, these programs use 14 medical crew and four pilots per helicopter. Based on the survey response, it is assumed that approximately 70 such programs do not currently provide their crew with fire-resistant uniforms, leaving 980 medical crew and 280 pilots unprotected. Each crew member needs two flight suits per year. The cost of poly-cotton flight suits is estimated at $150 each or $300 per crew member per year. Nomex flight suits cost $200 each. Equipping unprotected flight crews with Nomex would cost an additional $100 per year per crew member, or $28,000 for all the unprotected pilots and $98,000 for all the unprotected medical crew.

For the risk of burn injury, a survivable post-crash fire incidence of 14% was used. This figure, provided by Coltman, was used since NTSB crash records do not identify survivable crashes in which the occupants perished because of burn injuries.[5] Risk of fatal injury was developed from Knapp's research, which indicated that 63% of all survivable post-crash fire injuries were fatal.[12] Values used in the cost-effectiveness calculation are presented below and are based on a five-year period:

1) 4.3 survivable crashes per year;
2) Survivable post-crash fire rate of 14%, fatality rate of 63% among those exposed;
3) 6.2 crew members and 3.1 pilots at risk over a five-year period;
4) Nomex is 50% effective in preventing thermal fatality and reducing injury severity;
5) Benefit of fatality prevented = $629,600, severe injury prevented = $171,696 (Miller)[17];

6) 6% discount rate for benefits of injury over five-year period;
7) 2.8 fatalities prevented, 1.7 serious injuries prevented; and
8) Total cost of Nomex = $562,603 over five years, total discounted benefit = $1,911,611.

The projected cost for each thermal injury prevented is –$299,780. This represents a net benefit.

Energy Absorbing Seat (EAS) Cost-Effectiveness

Currently no seat manufacturer provides EAS for medical crew member stations in civilian helicopters. Discussions with Simula and Erda, both seat manufacturers, indicate they are planning to develop EAS in the near future. While cost figures were not yet finalized, the estimated range was $8,000 to $10,000 per seat.

For this analysis, the useful life of a seat is set at 20 years. Each helicopter will need a minimum of two medical crew seats and one pilot seat for a total of 600 seats. The analysis is conducted for both pilots and medical crew members separately since the frequency of back injury for each group is very different.

Medical Crew Members

The cost of equipping the fleet with EAS for crew members is $20,000 per ship or $4,000,000 for an entire fleet of 200 helicopters. Injury rates were developed for serious injury (involving spinal cord trauma), moderate injury (fractures and dislocations) and minor injury, including sprains and strains. The basic assumptions used in the calculations are highlighted below:

1) 4.3 survivable crashes per year;
2) Injury rates of the following severity levels: minor = 8%, moderate = 14%, serious = 5%;
3) Seat-effectiveness rates of 100% for serious injury reduction, 90% for moderate injury reduction, 80% for minor injury reduction were used;
4) Benefit of serious injury prevented = $567,600, moderate injury prevented = $122,053, minor injury prevented = $9,425 (Shanahan)[6];
5) 6% discount rate for benefits of injury over a 20-year period;
6) 10.75 minor, 21.55 moderate and 8.0 serious back injuries prevented over the 20-year period; and
7) Total cost of EAS for crew members over 20 years = $4,000,000, total benefit of injuries prevented over 20 years = $4,413,724.

The projected cost for each back injury prevented is –$10,266. This represents a net benefit.

Pilots

The cost of equipping the fleet with pilot EAS is $10,000 per ship or $2,000,000 for the entire fleet of 200 helicopters. Injury rates were developed for serious injury (involving spinal cord trauma), moderate injury (fractures and dislocations) and minor injury (sprains and strains). The basic assumptions used in the calculations are highlighted below:

1) 4.3 survivable crashes per year;
2) The following injury rates were used for the following severity levels: minor = 8%, moderate = 14%, serious = 5%;
3) Seat-effectiveness rates of 100% for serious injury reduction, 90% for moderate injury reduction, 80% for minor injury reduction were used;
4) Benefit of serious injury prevented = $567,600, moderate injury prevented = $122,053, minor injury prevented = $9,425 (Shanahan)[6];
5) 6% discount rate for benefits of injury over a 20-year period;
6) 2.7 minor, 5.1 moderate and 1.90 serious back injuries prevented over a 20-year period; and
7) Total cost of EAS for pilots over 20 years = $2,000,000, total benefit of injuries prevented over 20 years = $1,037,818.

The projected cost for each back injury prevented is $99,625. This represents a net cost.

Helmet Effectiveness

For this analysis, helmets are assumed to last for 10 years. The cost of a helmet is set at $700 per unit. While many programs provide helmets for each individual who flies, this analysis is based on four helmets for the medical crew on each helicopter and two helmets for the pilots. Two separate analyses were conducted for both pilots and medical crew. One analysis was predicated on the historical head injury exposure rates of EMS helicopter occupants. However, as mentioned earlier, there is a serious bias in these data that minimizes the severity of the occupant's injury (see section on study limitations). For this reason, the cost-effectiveness of helmets using U.S. Army head injury exposure rates is presented for comparison.[9]

Medical Crew

According to the survey responses, approximately 48% of the air medical helicopter program crews are currently flying with helmets. Using a fleet size of 200 helicopters, that means 104 ship sets are needed. Cost per ship is $2,800 for medical crew, requiring $291,200 to equip the fleet. The following assumptions were used in this analysis:

1) 4.3 survivable crashes per year, over a 10-year period, 84 medical crew at risk for injury;
2) The following injury rates were used for the following severity levels: minor = 3%, moderate = 3.9%, serious = 2%;
3) Helmet-effectiveness rates were set at 75% for serious injury reduction, 85% for moderate injury reduction, and 100% for minor injury reduction;
4) Benefit of serious injury prevented = $176,063, moderate injury prevented = $14,954, minor injury prevented = $4,684 (Miller)[18];
5) 6% discount rate for benefits of injury over a 10-year period;
6) 2.5 minor, 3.2 moderate and 1.8 serious head injuries prevented over a 10-year period; and
7) Total cost of helmets for medical crew over 10 years = $291,200, total discounted benefit of injuries prevented over 10 years = $258,652.

The projected cost for each head injury prevented is $4,339 over the 10-year period. This represents a net cost.

Pilots

The following assumptions were used in place of those mentioned above. At two helmets per ship, 104 ship sets needed, cost per ship is $1,400 for medical crew, requiring $145,600 to equip the fleet. The following assumptions were used in this analysis:

1) 42 pilots at risk for head injury;
2) 0% minor, 0.294 moderate and 0.546 serious head injuries prevented over the 10-year period; and

3) Total cost of helmets for pilots over 10 years = $145,600, total discounted benefit of injuries prevented over 10 years = $62,079.

The projected cost for each head injury prevented is $99,429 over the 10-year period. This represents a net cost.

Alternate Head-Injury Exposure Rates

Alternate exposure rates based on U.S. Army crash experience were used for comparison and to control for the serious coding and investigator bias present in NTSB crash records. The U.S. Army rates were chosen since they collect far more detailed injury information during a crash investigation and have done significant research on head injury and helmet use among helicopter aviators.

For this analysis, data on both medical crew and pilots were combined since U.S. Army research findings are often not stratified by occupant position. The following assumptions were used in this analysis:

1) There are 126 pilots and medical crew at risk for involvement in a survivable crash over the 10-year period. Of these, 72 are likely to be injured;
2) Six helmets are needed per ship, 104 ship sets are needed, cost = $436,800;
3) 8% of those likely to be injured are at risk for minor head injury, 16.3% are at risk for serious head injury and 7.7% are at risk for fatal head injury. These rates are predicated on research conducted by Crowley[9];
4) Helmet-effectiveness rates are assumed to be 50% for fatal head injury protection, 75% for serious head injury protection and 100% for minor head injury protection;
5) 5.53 fatal head injuries, 11.49 serious head injuries and 5.74 minor head injuries are projected to be preventable with the use of helmets;
6) Cost of head injuries is set at $4,684 for minor injuries, $14,954 for serious, and $629,600 for fatal; and
7) Total discounted benefits for injury presented is $1,479,666.

Table 10

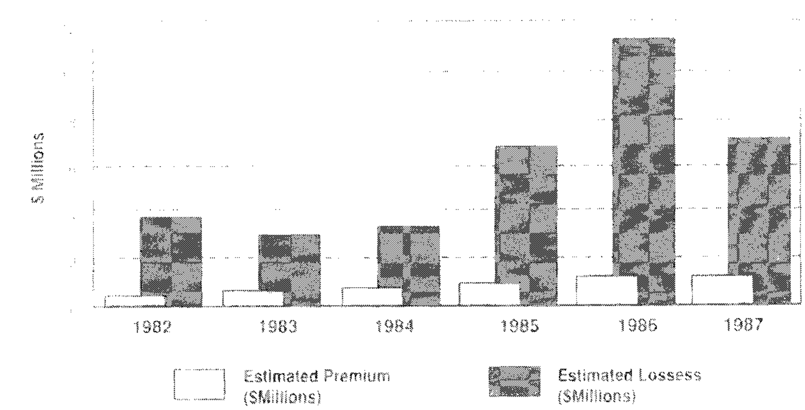
Intervention Cost-Effectiveness

Intervention	Population	Injuries Prevented/Year	Net Cost (+) or Benefit (-)	Cost per Injury
Helmets, Dodd rate	Medical crew	7.5/10 years	+$32,548	+$4,339
	Pilots	0.84/10 years	+$83,521	+$99,429
Helmets, Crowley rate	Crew/pilots	22.76/10 years	-$1,042,866	-$45,820
Energy-absorbing seats	Medical crew	40.3/20 years	-$413,724	-$10,266
	Pilots	9.7/20 years	+$962,182	+$99,194
Fire-resistant uniforms	Crew/ pilots	4.5/5 years	-$1,349,008	-$299,780

Figure 4

Estimated Liability Costs

(Total Estimated Loss: $55.02 million total or $390,212 per occupant, 1994 dollars)



The projected cost for each head injury prevented is -$45,820 over the 10-year period. This represents a net benefit.

Combined Findings

The combined findings of the above analyses are presented in Table 10.

These benefits were determined without accounting for liability costs, since current liability settlement figures were not available. However, insight can be gained on the potential influence of liability costs on this study. Figure 4 presents data provided by an aviation insurance representative concerning EMS helicopter liability costs experienced through the mid-1980s.[31] The differentiation of settlements to crash survivors compared with those who died was not possible. The estimated cost per occupant was estimated by dividing the total liability costs between 1982–1987 by the number of occupants involved in EMS helicopter crashes for those years.

Limitations

Certain limitations must be kept in mind when reviewing the results of this study. Each of the major considerations are discussed below.

Limitations of Cost-Effectiveness Analyses

It should be recognized that the results of cost-benefit or cost-effectiveness analyses should not be used as the sole determinant in making a decision about the implementation of an intervention program. Cost-effectiveness analysis strives to measure numerous factors that cannot be measured exactly or even accounted for. In most cases, what is being measured is actually being estimated. If the basic assumptions are in error, the result of the analysis also will be in error. Consequently, the results of a cost-effectiveness study can best be used as an aid in decision-making in combination with other sources of information.

Limitations of NTSB Crash Records for Injury Determination

The EMS crash data derived from the NTSB crash record have two major limitations that need to be considered when reviewing the results of this study. Both of these factors lead to a serious underestimation of the incidence and seriousness of the injuries sustained by the occupants.

The first problem relates to an "investigator bias." This bias is due to investigators not collecting detailed injury information consistently for all crashes. This is particularly noticeable with more serious survivable crashes where occupants are killed. The NTSB investigator usually will provide only the fact that the occupant died due to trauma. Conversely, investigators usually do not provide any detailed information about specific injuries that occur during less serious crashes. This bias has been noted by numerous aviation injury researchers including Coltman. The end effect is a serious underassessment in both injury severity measures and injury detail.

The second problem relates to efforts to overcome this investigator bias. In this study, actual narrative, witness statements and survivor interviews were used to gain a better understanding of an occupant's injury experience. When the information was not clear, or the severity could not be accurately assessed, the most conservative estimate was chosen. This too resulted in an underassessment of the injury severity and frequency.

These biases result in undercount and underassessment of the injuries experienced by EMS helicopter occupants involved in survivable crashes. As a result, the cost-effectiveness estimates are likely to be conservative in nature; that is, they understate the true positive effect of the interventions.

Small Size of EMS Helicopter Population

The small number of helicopters involved in air medical operations, and the even smaller number that crash in a given year, make future projections of crash risks uncertain—a small change in the number of crashes in either direction can have a profound effect on the applicability of these findings. The lifetime crash experience of the commercial EMS helicopter industry was used as the basis for the crash-trend projections, since that was known with certainty. Reductions in the crash rate over the projected time periods used in this study will result in less benefit from the benefits profiled. Conversely, an increase in crashes over that time period will likely increase the benefit.

Discussion

This study suggests that certain injury prevention interventions will have a positive effect in reducing the incidence and severity of injuries among EMS helicopter occupants in survivable crashes. Those which demonstrate the greatest potential estimated benefit per injury prevented include Nomex uniforms, helmets for pilots and crew, and EAS for medical crew members.

These findings should be considered as estimates since small changes can have a large influence on the outcome. For example, inclusion of one additional fatality prevented or an additional disabling head injury in these calculations would skew the results dramatically toward making the interventions even more cost-effective. This is due to the relatively small costs of incorporating these interventions into the fleet. Additionally, the inclusion of the liability costs presented in Figure 4 would have a strong positive effect on the cost-effectiveness for each injury prevented.

Clearly, the literature indicates that each of the interventions is effective in reducing injury risk. Helmets certainly reduce the risk of serious head injury. At a minimum, the risk is reduced by one-half, but there is convincing evidence that helmets reduce the risk of a fatal head injury eightfold, a highly significant level. Nomex flight-suit effectiveness was harder to determine. For this analysis, it was arbitrarily set at 50%. But the high risk of post-crash fire identified by Coltman, and the extremely high risk of fatal or very serious injury if a fire does occur as identified by Knapp, makes the argument for Nomex easier to understand. The high cost-effectiveness of Nomex identified in this study is due to the high cost of thermal fatalities and injuries and the very minor cost of Nomex compared to poly-cotton uniforms. It was not due to the large number of occupants being at risk for post-crash fire injury. This is a good example of the influence of large injury costs on outcomes mentioned earlier.

Energy-absorbing seat effectiveness was also well-documented. The high vertical survivable impact was identified as the greatest risk for occupants of civilian helicopters due to spinal injury. The literature indicates that EAS systems will reduce spinal injury risk and severity. In fact, Coltman indicated a 4% to 5% spinal injury rate with EAS, and those injuries would be minor. Shanahan indicated that 80% of current spinal injuries would be reduced or eliminated with EAS. The cost-effectiveness of this intervention was less clearcut due to the expense of equipping the fleet. Although there was a positive cost-effectiveness seen for medical crew, the same effect was not seen for pilots.

There are some other factors that should be considered while reviewing these results. No adjustment was made for the cost of current noncrashworthy medical crew seats in the analysis, since all current aircraft would have to be retrofitted with the new seats. The cost of the noncrashworthy seats should be considered, however, for those cases in the future when a new helicopter is modified. The real cost for the crashworthy seats in that case would be the difference between the old-style seats and EAS seats. This would certainly reduce the price of equipping the fleet. It should also be recognized that larger Bell helicopters have crashworthy pilot seats as a no-cost option from Bell. If these options were exercised, it would also reduce the cost to equip the fleet. Additionally, any newly type-certificated (newly designed and manufactured) helicopters, such as the McDonnell Douglas Explorer, will be required to meet the new FAA crashworthy standards. These standards will require protection for occupants up to 30 fps of vertical impact. It is likely that crashworthy seats will be incorporated in the aircraft to meet this requirement.

Shoulder harnesses are almost universal at all occupant positions in EMS helicopters according to the results of the survey. The cost-effectiveness of equipping the last 6% to 8% of the fleet was not determined, since the effectiveness of harnesses in reducing *specific* injuries has not been well-documented among helicopter occupants. The *cumulative* benefit of shoulder harnesses, however, is well-documented and quite impressive. The weight of that evidence is so persuasive that every EMS helicopter not equipped with shoulder harnesses should have them installed immediately.

The applicability of the injury experience of military helicopter occupants often has been cited in the EMS helicopter community as not being the same as civilian operations. While it is true that sex and age distributions are different between the two groups, there are more similarities than differences. The real issue in any evaluation of crashworthiness is not the type of aircraft that crashes, but rather the forces experienced by the individual occupants as a result of the crash. If an occupant experiences 40gs of loading in a military helicopter or the same force in a civilian helicopter, the results are likely to be the same. It could be argued, however, that civilian EMS helicopter interiors provide a more hazardous environment in a survivable crash than military utility helicopters, since the military helicopters typically have more room and less equipment in the interior.

The one factor that is different between the military and civilian EMS helicopter populations is age. Tolerance to injury is inversely related to age. The older one is, the more likely he or she is to be injured compared with a younger person exposed to the same injury cause. This factor, however, would tend to make the EMS helicopter occupant more prone to injury compared with the occupant of the military helicopter, since the mean age of EMS helicopter occupants is 26 years old.[3]

Conclusions and Recommendations

The findings from this analysis presented each injury as an independent event. In reality, multiple injuries often occur among occupants of helicopters that crash. In those cases, the joint effect of multiple injuries is greater than their sum. Thus, the interventions discussed in this study should be considered in combination, not separately. For example, a Nomex uniform provides little protection if the wearer experiences a head injury that renders him or her unconscious for 15 seconds after impact. Nomex will only provide the occupant some additional seconds for escape, not unlimited protection. For crashworthiness to work, it must use a systems approach.

Crashworthiness will become the standard in EMS helicopter operations as newly designed helicopters are marketed and join the fleet. In the interim, improvements can be made to reduce the risk of injury to medical crew and pilots in survivable crashes. This study provides evidence that Nomex uniforms, helmets and EAS for medical crew members will prove cost-effective in reducing preventable injuries in survivable crashes.

Emergency medical services helicopter operations involve certain risks that should be considered occupational hazards. Those who make their living as EMS helicopter pilots or medical crew should receive the benefit of equipment that reduces these hazards. EMS helicopter occupants should wear fire-resistant uniforms and helmets. Medical crew members should have EAS systems when they become available. EAS systems are also recommended for the pilots, although they were not shown to be cost-effective based on the projections developed in this study.

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Endnotes

a. The crashworthiness of an aircraft relates to those features designed to enhance occupant survival in a survivable crash.

b. Crashes are considered survivable if the accelerations are within the limits of human tolerance and enough space remains for properly restrained (lap and shoulder harness) occupants. The effects of post-crash fire are typically not considered. Helicopter occupants are often seriously injured in survivable crashes, and sometimes die.

c Crash forces are often measured and described by changes in velocity, usually feet per second. Occupant protection levels are often described in g's experienced. G loading takes into account occupant weight and time of exposure.

d. Some Bell helicopters incorporate improved crashworthiness protection above this level for vertical impact scenarios.

e. FAA crashworthiness requirements have recently changed for newly designed and certificated helicopters. These new regulations require helicopters to provide protection to occupants in vertical velocity changes of 30 feet per second. Currently manufactured helicopters do not have to meet these new standards. The first production helicopter designed to these standards will be the McDonnell Douglas Explorer (FAR part 27.562).

f. A crashworthy fuel system includes crash-resistant fuel cells, high strength tank fittings, and breakaway self-sealing valves that prevent fuel spillage if fuel lines rupture. The majority of civilian helicopters do not incorporate complete crashworthy fuel systems, but some do include selected components.