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Projected Effectiveness of Airbag Supplemental Restraint Systems in U. S. Army Helicopter Cockpits

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Despite significant advances in accident prevention, crashworthiness, and individual protective equipment, head and torso injuries continue to cause death and disabling injuries in survivable Army helicopter accidents. Most of these injuries are caused by the occupant striking internal structures. The purpose of this study was to review Army helicopter accident records to determine the number of fatal and disabling injuries in pilots and copilots that could be prevented with the introduction of an airbag supplemental restraint system into U.S. Army helicopter cockpits.

Computerized records from the U.S. Army Safety Center of all class A and B mishaps of the six most commonly used helicopters from October 1983 through September 1992 were reviewed. A computer model was developed to identify cockpit crewmembers who would have reduced severity of injury if the mishap helicopter were equipped with a proposed three-bag

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airbag supplemental restraint system. The model considered severity and mechanism of injury as well as the type helicopter and dynamics of the crash. Over the 9-year study period, we identified 30 fatalities and 11 crewmembers with disabling injuries that could have been prevented with an airbag system. Including the hospital costs of lesser injured individuals, the estimated annual injury cost savings associated with an effective cockpit airbag system was approximately $4.3 million.

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Introduction

In 1908, while flying with Orville Wright, an unhelmeted Army pilot named Thomas Selfridge became the first powered aircraft fatality when he suffered lethal head injuries in the crash of a Wright Flyer (Combs, 1979). Despite all efforts to the contrary, aircraft have continued to crash with alarming regularity resulting in the deaths and injury of people throughout the world. Recognizing that aircraft will continue to crash in spite of advances in aviation safety and aircraft reliability, regulators, manufacturers, and operators have placed increasing emphasis on aircraft crashworthiness and individual protective equipment. These improvements have reduced significantly the potential for injury in crashes of aircraft designed to modern crashworthiness standards (Shanahan and Shanahan, 1989). The U.S. Army has been a world leader in instituting improvements in crash protection and was the first service to develop and implement crashworthiness design standards (Department of Defense, 1988 and Department of the Army, 1989). In spite of these advances, injury, and particularly head injury, continues to be a major problem in crashes of U.S. Army helicopters (Bezreh, 1961; McMeekin, 1985; and Shanahan and Shanahan, 1989).

Addressed in MIL-STD-1290A (1988) are five basic areas of aircraft design that should be considered in order to provide protection for the occupants in the event of a crash:

a. Structural crashworthiness. Ensuring the aircraft structure maintains livable space for occupants throughout a crash.

b. Occupant load limitations. Ensuring the loads on the occupants do not exceed the range of human tolerance through the use of crushable structure, load limiting landing gear and load limiting seats.

c. High mass item retention. Ensuring high mass items such as rotor blades, transmissions, and engines do not penetrate occupied areas during a crash.

d. Noninjurious interior. Providing optimum occupant restraint and adequate padding, frangibility, or placement of potentially injurious interior items to prevent injury from occupant flailing during a crash.

e. Postcrash protection. Providing protection from fire in the postcrash environment through containment of flammable fluids and reduction of ignition sources. Also, providing adequate avenues of egress for all occupants.

To provide crash protection for occupants of Army helicopters, current helicopters include crash resistant fuel systems, lap and upper body restraints, and, in some helicopters, energy-absorbing landing gear and seat systems. Personal protective equipment worn by the aviator includes a flight helmet, survival vest, and fire resistant flight clothing. These enhancements significantly reduce the risk of injury and death for Army personnel involved in aircraft accidents. For example, the introduction of crash resistant fuel systems into most Army helicopters in the 1970s reduced the incidence of thermal deaths in survivable crashes to a negligible level (Shanahan and Shanahan, 1989). Also, Crowley (1991) reported less than one-sixth the number of fatal head injuries in Army helicopter crashes for occupants who wore protective helmets versus those who did not.

Although advances in crashworthiness of Army helicopters and in personal protective equipment have greatly reduced the potential for serious injury in a crash, a recent study of injury in Army helicopter crashes showed that five out of six injuries were due to occupants striking aircraft structure. This occurred even though occupants wore seat belts and upper torso harnesses and, in most cases, protective helmets (Shanahan and Shanahan, 1989). A feasibility study of incorporating airbags into attack helicopters further showed that a simple airbag system reduced most head injury severity indices by as much as 70 percent in simulations of severe crashes (Alem et al., 1992). The purpose of this study was to review Army helicopter crashes to determine if an airbag system incorporated into Army cockpits would reduce the number of fatal and serious nonfatal injuries for cockpit crewmembers in crashes.

Materials and methods

Information on all U.S. Army class A and B helicopter mishaps over the 9-year period from 1 October 1983 through 30 September 1992 was obtained through the Army Safety Management Information System (ASMIS) of the U.S. Army Safety Center (USASC). Class A mishaps are defined by regulation as crashes for which the resulting total cost of property damage, occupational illness, or injury is $1 million or greater, or in which an injury results in a fatality or permanent total disability (Department of the Army, 1993). Class B mishaps are defined as crashes for which the total cost is greater than $500,000 but less than $1 million. The starting date of this study was selected to correspond with the initiation of ASMIS data recording of severity and mechanism of occupant injuries.

The current ASMIS database does not contain specific information for predicting the potential of an airbag to prevent injury of cockpit crewmembers in a given crash. Therefore, a computer algorithm was developed to use available injury data, estimated kinematic parameters, and other aircraft specific information to estimate the potential effectiveness of an airbag system. The modeled airbag system was a three-bag system with forward and lateral placement of the airbags (Figure 1, Department of the Army, 1991).

The analysis was limited to front seat occupants involved in crashes of UH-1, OH-58, CH-47, and UH-60 series helicopters and both occupants of AH-1 and AH-64 attack helicopters. A crash was defined as a Class A or B mishap where the vertical velocity at primary ground impact exceeded zero. This vertical velocity limitation eliminated mishaps occurring during ground operations, mishaps involving obstacle collisions where the helicopter was subsequently able to land safely, and mishaps where personnel or material fell from the helicopter during flight.

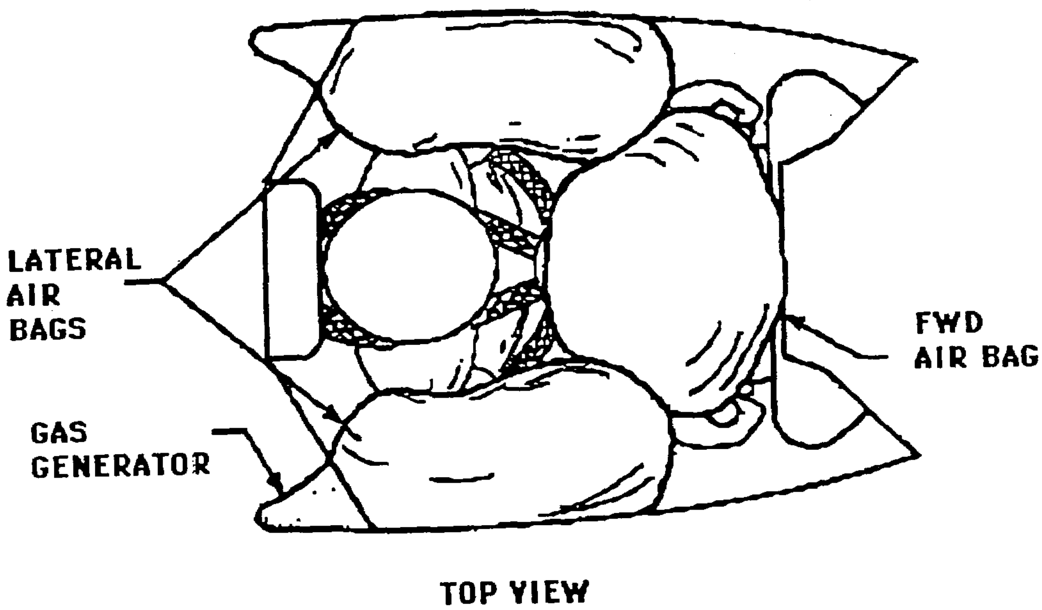

Figure 1. Proposed three-bag airbag system for U.S. Army attack helicopters.

Computer modeling

The algorithm first determined the most severe injury for each individual. Then a Poisson regression model was used to determine the threshold of fatal injury for each major impact parameter including vertical velocity, longitudinal velocity, and helicopter attitude (pitch, roll, and yaw). The threshold value of each parameter was selected to be the point where fatal injury became significant at the 0.05 level after controlling for the other variables. Aircraft type was dichotomized into precrashworthy (designed before the introduction of MIL-STD-1290 standards) and crashworthy (UH-60 and AH-64). Each helicopter was coded into one of four functional groups: attack, observation, utility, or cargo.

It was essential to exclude from consideration those crashes which occur at such extreme velocities or attitudes that resulting accelerations or structural deformations would create an environment where survival would be impossible even with an effective airbag system. To accomplish this, the threshold values of crash kinematic parameters for fatal injury determined by the Poisson regression model were used to exclude from consideration all crashes which exceeded potentially survivable limits. The threshold value for longitudinal velocity for fatal injury (the point at which longitudinal velocity became significant in the model) was 100 ft/s, the threshold value for pitch angle was -5 degrees (pitch down) and +10 degrees (pitch up) with a second, smaller threshold at -10 and +30 degrees. The threshold for roll was 35 degrees, and the threshold for vertical velocity was 60 ft/s for precrashworthy helicopters and 85 ft/s for crashworthy helicopters. While we expected a difference in threshold values among helicopter types (attack, observation, utility, cargo), the data did not support this hypothesis. This may be due to the overwhelming effect of crashworthy versus precrashworthy design and the relatively small number of crashes of certain helicopters (AH-64 and CH-47) available for study.

After excluding crashes with excessive kinematic parameters, the algorithm examined each remaining crash and determined which injuries would have been prevented by an airbag system. A preventable injury was defined as an injury to the head, neck, chest, abdomen, or upper arm that was coded as major, critical, or fatal, with a mechanism of injury identified as "struck by," "struck against," or "caught in/under/between." Minor injuries such as abrasions, small lacerations, and contusions were excluded from consideration. If the injury mechanism was "exposed to" or "experienced," the injury was considered preventable except when the injury was coded as caused by excessive g-forces or multiple injury-causing mechanisms. In the case of injuries caused by thermal or chemical burn, the injury was considered preventable if other injuries would not have precluded the crewmember from exiting the aircraft immediately after impact. This decision was made because postcrash fires in potentially survivable crashes of helicopters equipped with crash resistant fuel systems usually occur after the crew has had adequate time to escape the aircraft. We also set as not preventable any injury that occurred before impact, since the airbag would deploy only on impact. Internal injuries defined as lacerations (liver, spleen, great vessels, etc.) were not considered preventable because they are caused frequently by excessive acceleration and not by striking an internal object.

Finally, the algorithm estimated the expected degree of injury of each individual if the helicopter had been equipped with a functioning airbag system. This was accomplished by reviewing every injury reported for each injured crewmember and eliminating the injuries considered preventable with an airbag system. The remaining injuries were used to determine the degree of injury expected for the same crash with an airbag-equipped helicopter. Thus, a fatality was considered preventable if all fatal injuries sustained by the individual were preventable with an airbag. Depending on the remaining injuries, this individual would be classified with some lesser degree of injury or no injury.

It should be emphasized that the airbag system was considered to be 100 percent effective in preventing contact injuries of the upper torso if the crash was determined to be potentially survivable. We recognize this is an overly optimistic assumption due to the potential for "bottoming out" of the bags in severe but survivable impacts or failure to remain inflated throughout an extended crash sequence. However, since inflation parameters for an airbag system are not yet determined and since such events will occur rarely, we believe the assumption is appropriate for the purposes of this study.

The cost of airbag preventable injuries was calculated using the injury costs specified in AR 385-40 (1993). This regulation specifies the cost for a flying officer fatality at $1.1 million, permanent total disability (critical injury) at $1.3 million, and permanent partial disability (major injury) at $210,000. We used the degree of injury code in the ASMIS database to determine the severity and cost for preventable injuries.

Results

From 1 October 1983 through 30 September 1992 there were 282 Army Class A and B mishaps of the six helicopter types considered in this study (Table 1). These crashes resulted in 128 fatalities, 26 aviators with disabling injuries, and 176 with injuries sufficient to require hospitalization or days away from work.

Table 1.

U.S. Army rotary-wing mishaps, FY 84-92.

Helicopter type	Classification of mishap		
	A	B	Total
AH-1	27	13	40
AH-64	18	2	20
CH-47	10	3	13
OH-58	70	7	77
UH-1	80	12	92
UH-60	32	8	40
Total	237	45	282

Table 2 summarizes these injuries for each helicopter type using the Department of Defense classification for degree of injury as reported in the ASMIS database (Department of the Army, 1983).

Table 3 summarizes the estimated monetary cost of the injuries sustained by cockpit crewmembers over the 9-year period of the study. For purposes of comparison, these costs have been delineated by helicopter type. There is not a complete correlation between Table 3 and Table 2 for the injury categories workdays away and workdays restricted as evidenced by zero costs being shown in cells of Table 3 where Table 2 shows a positive value. This is because, in order to estimate costs in these injury categories, it is necessary to know the total number of days the individual was away from work or on restricted activity. Since this information was not available in many reports, the decision was made to err on the conservative side by showing zero cost rather than speculating on the number of days the individual was away or restricted. This results in a small underestimation of total injury cost since the costs associated with days away or days of restricted activity are relatively insignificant compared to higher degrees of injury (Table 2).

Note that the magnitude of injury cost for any particular helicopter series is dependent upon the mishap rate and the number of hours flown over the period as well as the severity of the crashes. Therefore, high injury costs associated with a particular helicopter type may be more dependent upon the number of airframes in the fleet and the hours flown (total exposure) than upon any deficiency in design or operation.

Table 2.

Degree of injury for cockpit crewmembers involved in U.S. Army class A and B rotary-wing crashes, FY 84-92.

Degree of injury	Helicopter type						
	AH-1	AH-64	CH-47	OH-58	UH-1	UH-60	Total
Fatal	24	7	7	31	35	24	128
Permanent total disability	0	0	0	1	1	1	3
Permanent partial disability	1	2	0	10	5	5	23
Workdays away	13	16	2	41	49	23	144
Workdays restricted	2	4	4	11	10	1	32
No lost workdays	2	0	0	3	2	4	11
First aid only	10	4	3	21	26	8	72
No injury reported	28	7	10	33	55	14	147
Total	80	40	26	151	183	80	560

Table 3.

Cost of injury to cockpit crewmembers involved in U.S. Army rotary-wing class A and B mishaps, FY 84-92 ($Million).

Degree of injury	Helicopter type						
	AH-1	AH-64	CH-47	OH-58	UH-1	UH-60	Total
Fatal	26.00	7.70	7.70	34.10	38.50	26.40	140.40
Permanent total	0	0	0	1.30	1.30	1.30	3.90
Permanent partial	0.25	0.50	0	2.50	1.25	1.25	5.75
Workdays away	0.02	0	0	0.02	0.36	0	0.40
Workdays restricted	0	0.06	0.01	0.02	0.04	0	0.13
Total	26.27	8.26	7.71	37.94	41.45	28.95	150.58

When the algorithm developed for this study was applied to each crash and each cockpit crewmember, the model predicted significant reductions in major injury assuming an airbag system was available at the time of each crash. Table 4 shows the number of crewmembers predicted to be "saved" from injury by an airbag for each injury category. Actual number of aircrew members "saved" as well as percent are shown. Note that zero indicates the model did not predict any reductions in injury with an airbag system for that particular cell. A period represents a missing value, indicating there was no injury reported in that cell prior to applying the model (Table 2). It is interesting that, in general, airbags are more effective in preventing nonfatal injuries. Also notice that the overall values in Table 4 can be used to estimate the potential effectiveness of retrofitting airbags to any particular helicopter type, assuming flight hours and severity of crashes remain relatively constant over time. This analysis indicates the highest rates of reduction for the AH-64 and AH-1, followed by the UH-1.

Table 4.

Estimated injury reductions associated with an airbag system in U.S. Army rotary-wing aircraft, FY 84-92

Degree of injury	Helicopter type						
	AH-1	AH-64	CH-47	OH-58	UH-1	UH-60	Total
Fatal	8 33.3%	1 14.3%	1 14.3%	9 29.0%	7 20.0%	4 16.7%	30 23.4%
Permanent total	.	.	.	1 100%	1 100%	1 100%	3 100%
Permanent partial	0	1 50.0%	.	2 20.0%	3 60.0%	2 40.0%	8 34.8%
Workdays away	10 76.9%	10 62.5%	2 100%	16 39.0%	25 51.0%	11 47.8%	74 51.4%
Workdays restricted	1 50.0%	3 75.0%	1 25.0%	2 18.2%	6 60.0%	1 100%	14 43.8%
Total	19 47.5%	15 51.7%	4 30.8%	30 31.9%	42 42.0%	19 35.2%	129 39.1%

In order to compensate for fluctuations in number of airframes and annual flight hours for each type of helicopter, injury costs with and without an airbag system were calculated based on 1992 utilization data (Figure 2). All Class A and B mishaps over the 9-year period of the study were used as the basis for the injury cost estimates. This analysis projects an annual injury cost savings ranging from approximately $750,000 to over $1 million for all helicopters except the CH-47. The highest annual payoff was for the OH-58 followed by the AH-1 and UH-60.

Figure 3 shows a similar analysis, but normalized to 100,000 hours of flight time. This figure shows that, assuming equivalent exposure (identical flight hours), airbags will yield the greatest reductions in injury costs for the AH-1, UH-60, and OH-58 series helicopters.

Table 5 provides an estimate of the number of years required to amortize the cost of retrofitting airbags to the helicopters included in this study. This analysis assumes fiscal year 1992 utilization levels and constant number of airframes. The cost of retrofitting an airbag system was estimated at $10,000 per airframe based the on the projected cost of the current prototype three-bag system. The amortization period varied from a low of 9.7 years for the AH-1 to over 33 years for the UH-1.

Discussion

The purpose of this study was to provide a basis for estimating the potential savings in injury and injury costs associated with incorporation of an airbag system into Army helicopter cockpits. Ideally, this study would have involved a comprehensive review of the narrative and photographic evidence of each mishap by a team of injury and crash investigation experts. Since such a study was beyond the time and resource constraints available, we elected to use the data in the Army Safety Management Information System database and construct a computer model to predict airbag effectiveness. The major technical advantages of this method other than economy are that it ensures repeatability and eliminates subjective judgments in determining individual injury outcomes. The major disadvantage is the method requires rigorous selection criteria based on data available in the ASMIS, and does not allow for adjustments based on photographic or narrative information. Nevertheless, considering the relatively long period covered by the study and the large total number of crashes, we believe this analytical method provides a reasonable and conservative estimate on which to base programmatic decisions. It should be stressed also that the available data covered only mishaps occurring during a period of relative peace. No combat losses are included in the ASMIS data

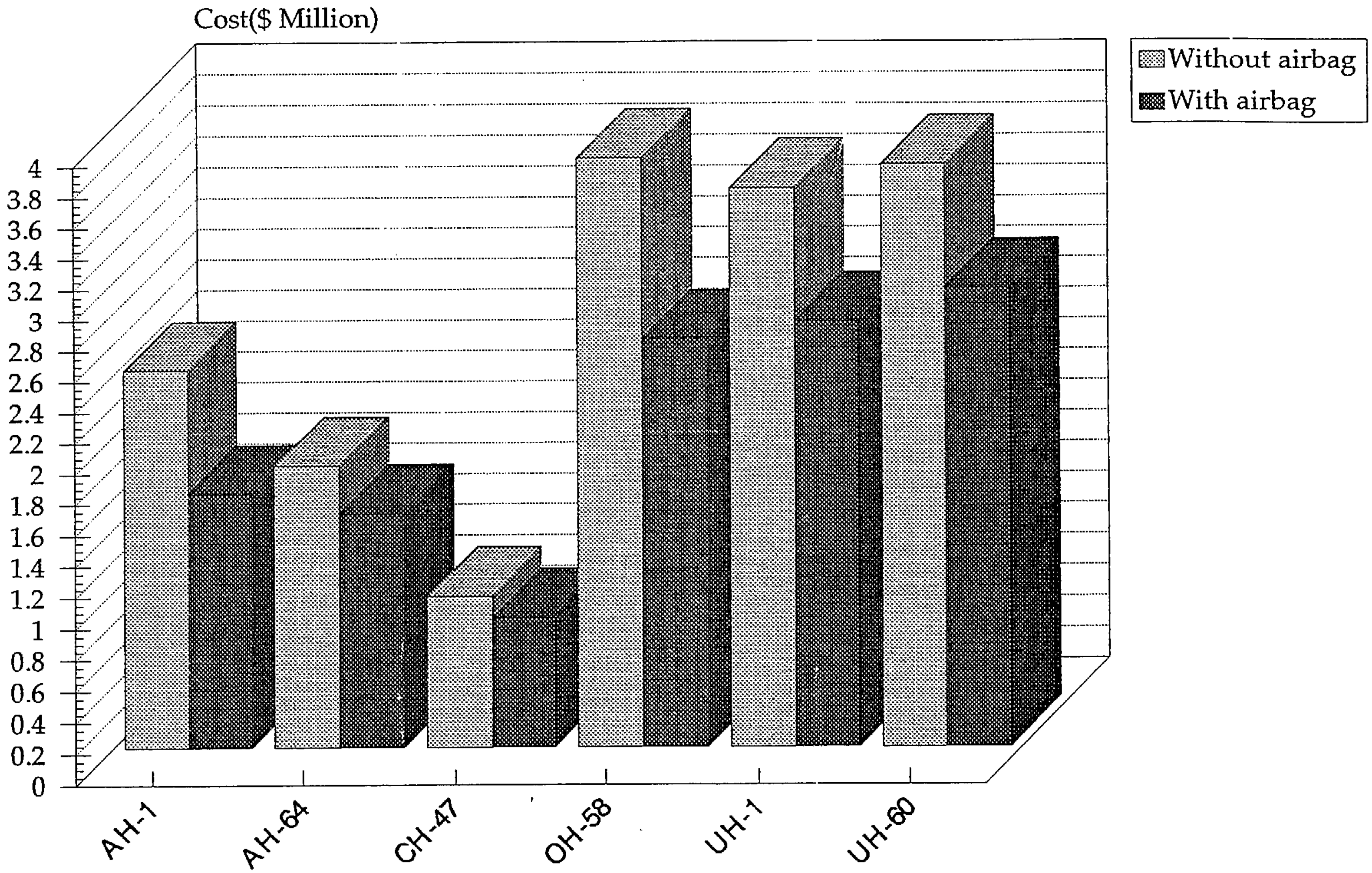

Figure 2. Estimated annual injury cost based on 1992 helicopter utilization without and with airbags.

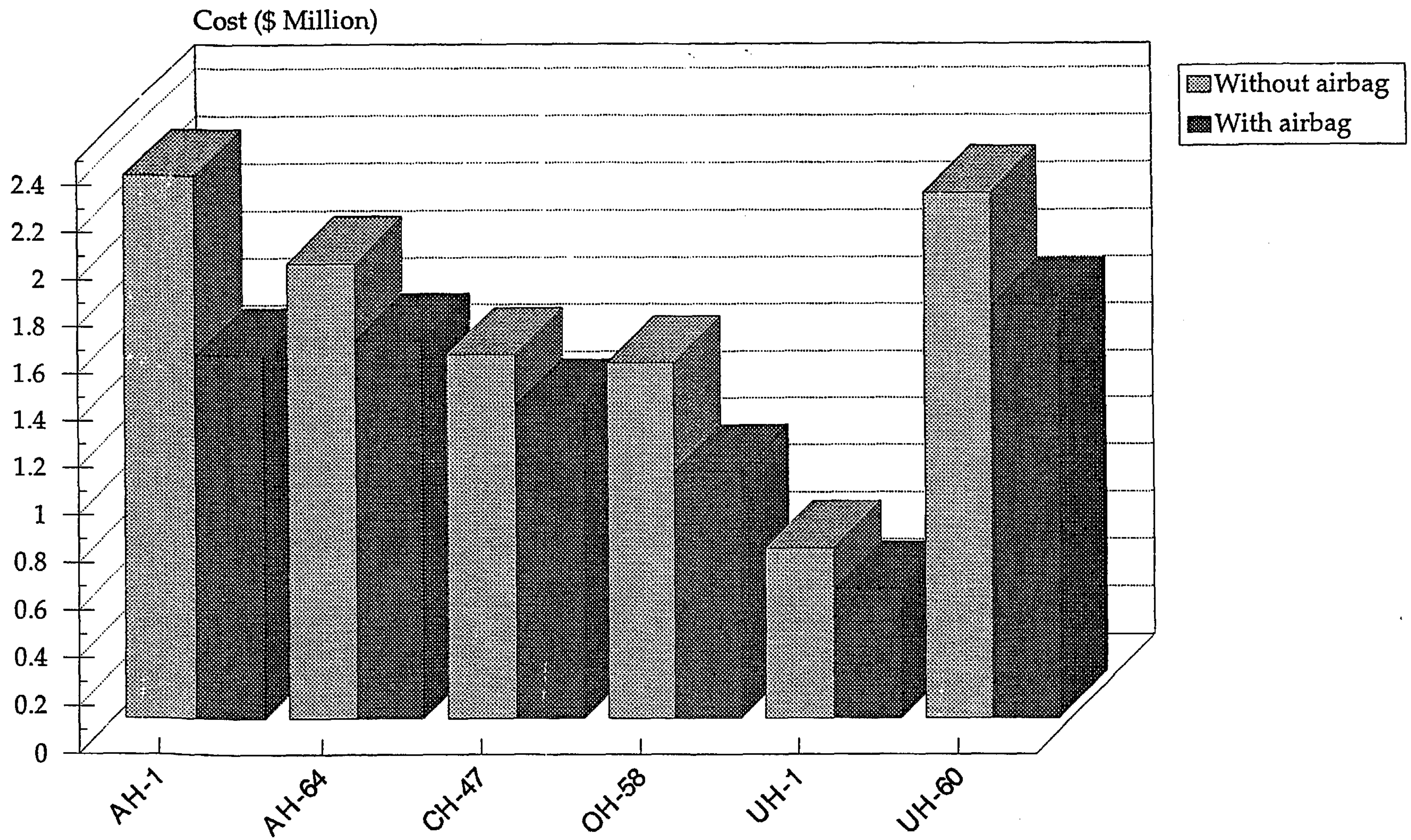

Figure 3. Cost of injury per 100,000 flight hours without and with airbags.

Table 5.

Projected amortization period to recoup the costs of retrofitting airbags into existing helicopter airframes.

	Helicopter type						
	AH-1	AH-64	CH-47	OH-58	UH-1	UH-60	Overall
1992 Flight hours	106,065	94,032	62,928	254,043	507,548	169,660	1,194,276
No. of airframes	780	658	422	1,876	2,884	1,150	7,770
Hours/airframe	135.98	142.91	149.12	135.42	175.99	147.53	153.70
Injury cost reduction/100K hours	$759K	$330K	$219K	$464K	$170K	$475K	$344K
Injury cost reduction/ airframe	$1,032	$471	$327	$628	$300	$701	$528
Years to recoup	9.7	21.2	30.6	15.9	33.4	14.3	18.9

and few of the cases occurred in combat zones. The effectiveness of an airbag system would be more apparent during wartime when the number of crashes due to mishaps and enemy action would be greatly increased.

The effectiveness of an airbag system measured in terms of lives saved or injuries prevented for a particular airframe depends on the number of crashes occurring over a period of time, the severity of these crashes, and the types of injuries typically associated with the crashes. The types or mechanisms of injury occurring in crashes is highly related to airframe design parameters and configuration of seating positions. Consequently, for a given crash pulse, certain airframes may be more prone to involve injury amenable to prevention by an airbag than others. An example of a configuration particularly suited to an airbag is Army attack helicopters which have nonfrangible gunsights located within the strike envelope of the copilot/ gunner. Airbags located on the gunsight have been shown to be very effective in reducing the probability of severe injury in these cockpits (Alem et al., 1992). In any case, the decision to retrofit an airbag system to any airframe should consider all potential factors to ensure achieving the expected results.

The model used in this study to predict airbag effectiveness was based on parameters derived from previous crashes of Army helicopters. Accident rates, crash severity and injury mechanisms were best estimated by considering the entire study period. However, since the UH-60 and AH-64 were being phased in over the period of study, projected annual flight hours would be severely underestimated if they were calculated as an average of the period. Conversely, over the same period, other airframes were being reduced in number which would result in an over-estimation of flight hours. For this reason, we chose to base our estimates of projected airbag effectiveness on the 1992 flight hours of each helicopter series (Figure 2 and Table 5).

Table 5 provides the best basis for comparisons between helicopter types because the estimates contained in it are based on a defined number of airframes and flight hours. Either parameter can be reset based on other projections of future utilization. These estimates show an airbag system would be most effective in preventing injury in the AH-1, followed by the UH-60 and the OH-58. The AH-64 would benefit somewhat less from airbags. To many, this result will appear surprising due to the apparent similarities in configuration and mission profile between the AH-1 and the AH-64. In spite of these apparent similarities, these helicopters actually perform quite differently in a crash. The AH-64 fuselage tends to fracture between the copilot and pilot seats i severe crashes which exposes the copilot to an extreme probability of severe or fatal injury which would not be reduced by the presence of an airbag. Conversely, the pilot position provides excellent protection against structural collapse. This factor, along with the presence of energy-absorbing landing gear and seats, provides an already low injury rate for the AH-64 pilot position in crashes which would not be greatly enhanced with an airbag. These two factors result in a relatively small projected benefit for an airbag system in the Apache.

Airbag supplemental restraint systems have proven themselves highly effective in preventing injury in automobile crashes. Although the crash environment of the helicopter is somewhat more complex, this analysis of helicopter injury data strongly suggests that a three-bag airbag supplemental restraint system would be extremely effective in Army helicopters. We estimate a 39.1 percent reduction in all injuries which would result in an injury cost savings of over $4.3 million per year if airbags were installed in the six most common helicopters in current use by the U.S. Army. Without considering the added benefit in reduced personal suffering and increased confidence and morale, the complete cost of such a retrofit program could be amortized in less than 19 years.

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