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# Engineering analysis of crash injury in Army OH-58A aircraft

UNITED STATES ARMY SAFETY CENTER  
TECHNICAL REPORT  
TR 78-1  
FEBRUARY 1980



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# Engineering analysis of crash injury in Army OH-58A aircraft

Directorate for Aviation Systems Management  
U.S. Army Safety Center  
Fort Rucker, Alabama 36362



Colonel E. E. Waldron II  
Commander

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## Foreword

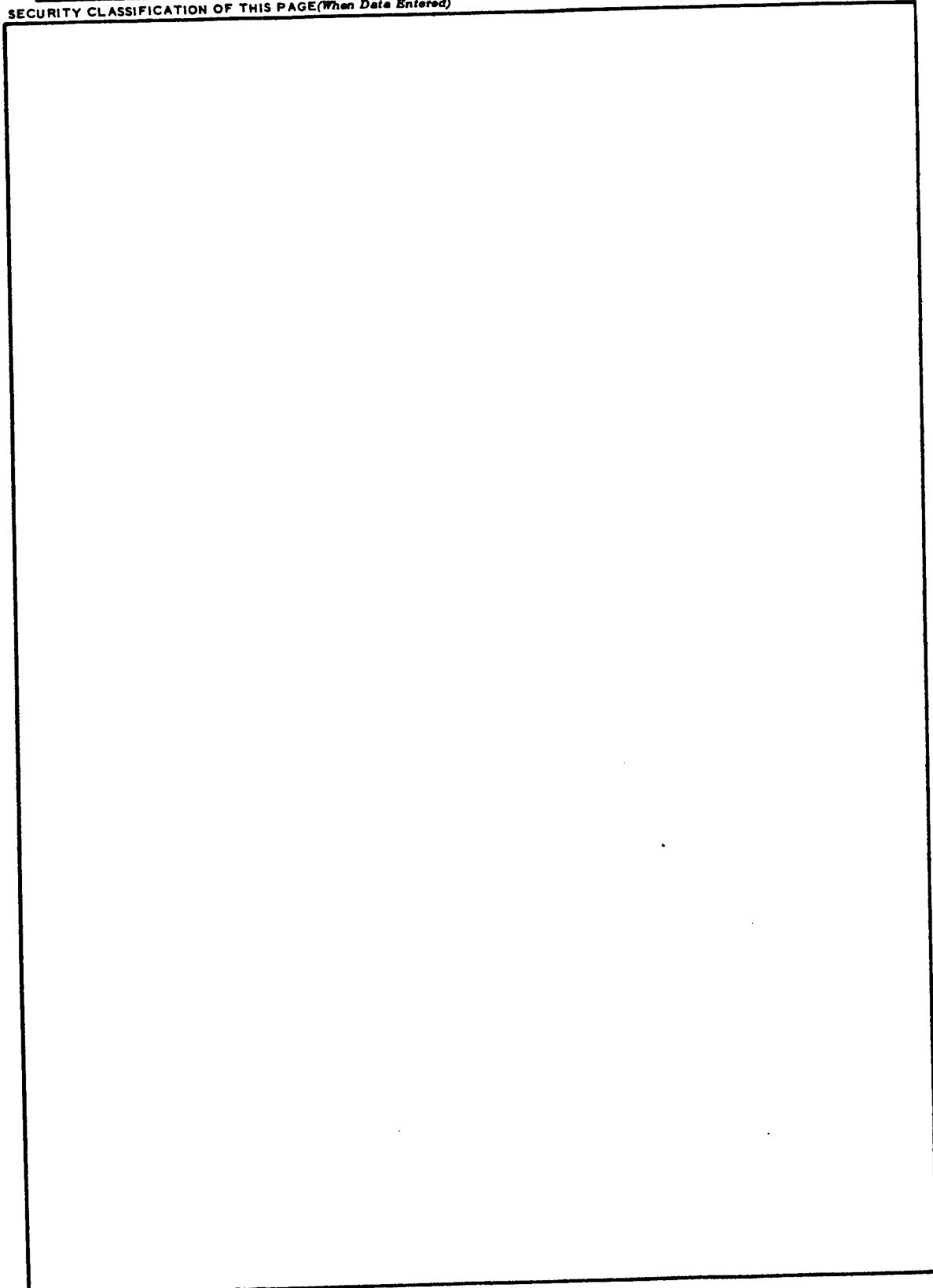
The analysis reported herein was performed by a study group formed by representatives of several Army agencies and commands. The U.S. Army Safety Center provided technical direction and management of the team. Participating agencies were the Applied Technology Laboratory of the U.S. Army Research & Technology Laboratories; Headquarters, Aviation Research and Development Command; Aeromedical Research Laboratory; and Armed Forces Institute of Pathology.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This is the report of an analysis of crash injury causes in U. S. Army OH-58 aircraft accidents. The analysis was performed to provide systematic direction to Army crash safety research and development. The data base for the analysis was all OH-58A major aircraft accidents which occurred during CY 1971-1976. Causes of crash injuries are identified, costed, and ranked to determine pressing crashworthiness research and development programs.			

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# Summary

This report contains the results of an analysis of crash injury causes in U.S. Army OH-58A aircraft accidents. The analysis was performed to provide systematic direction to Army crash safety research and development.

The data base for the analysis was all major aircraft accidents which occurred to OH-58A series aircraft during CY 71-76. The accidents were analyzed in detail by a study group formed by representatives of several Army agencies. This group determined the extent and underlying causes of crash injuries based on medical and engineering data contained in accident reports and related files. Crash hazards which resulted in the largest personnel losses were identified and prioritized to determine pressing crashworthiness research and development programs. The impact

conditions under which these crash hazards resulted in preventable injuries were summarized to aid in future determination of crashworthiness design criteria.

The study identified 20 separate crash hazards in OH-58As. It was determined that the research, development, and product improvement efforts which would result in the greatest benefits in reducing these hazards were (1) improved vertical energy absorption in aircraft structure and/or crew seats; (2) crewmember restraint systems with improved upper torso restraint; and (3) prevention of main rotor blade intrusion into crewstations.

This study also suggests that an improved method of determining crash impact conditions is necessary for accurate determination of future crashworthiness design criteria.

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# Engineering analysis of crash injury in Army OH-58A aircraft

## INTRODUCTION

A systematic technique for the identification of crash injury causes in Army aircraft accidents has been developed as reported in reference 1. This report documents the application of this technique to the Army/Bell Helicopter Textron OH-58A observation helicopter.

The goal of this analysis is the determination of the most critical crash hazards in current OH-58 aircraft and the identification of the most beneficial research programs to improve its crash survivability.

Similar studies of other major Army aircraft are planned.

## OBJECTIVES

The overall objectives of this study were to (1) identify the most significant OH-58A injury causes, (2) determine the extent of losses attributable to each, and (3) establish under what crash mechanisms and impact conditions each becomes a problem. Emphasis was placed on not merely documenting the types and frequency of injuries sustained but also on identifying their underlying causes. The analysis of the engineering causes of crash injury considered the presently documented human tolerance to acceleration. It was envisioned that a primary output of this effort would be an improved direction for crashworthiness research, including identification of follow-on efforts to define specific hardware to reduce the hazards in current and future aircraft.

## ASSUMPTIONS

The major assumptions of this analysis are as follows:

- Past aircraft accident data provide a valid baseline for establishment of future crashworthiness design criteria.

- The frequency and severity of crash injuries are the primary rationale and justification for research designed to reduce crashworthiness deficiencies.

- Additional rationale and justification for crashworthiness research are the costs of accidental injuries (reference 2).

- The aircraft fleet flying hour rate and rates of injury occurrence identified in the baseline study period are representative of a future 20-year period.

## APPROACH

**Data Sources.** The primary data source for this study was the case files of Army OH-58A series aircraft accidents occurring during calendar years 1971 through 1976. Accident data used was taken from the U.S. Army Safety Center files at Fort Rucker, Alabama. The 163 OH-58A aircraft accidents which occurred during this period are summarized in table 1. Appendix A contains definitions of terms used in table 1 and in other portions of this report. All costs were calculated in constant FY 76 dollars.

**TABLE 1.—U.S. Army OH-58A Aircraft Accidents, CY 71-76**

Number of accidents	163*
Number of accidents analyzed in this study	162**
Number of aircraft flight hours	1,918,947
Accident rate (per 100,000 flight hours)	8.5
Number of occupants	383
Number of occupants killed or injured	144

\*There were 164 OH-58A aircraft involved in the 163 accidents.

\*\*One OH-58A aircraft accident occurred which did not involve a crash impact. This accident was not included in this study.



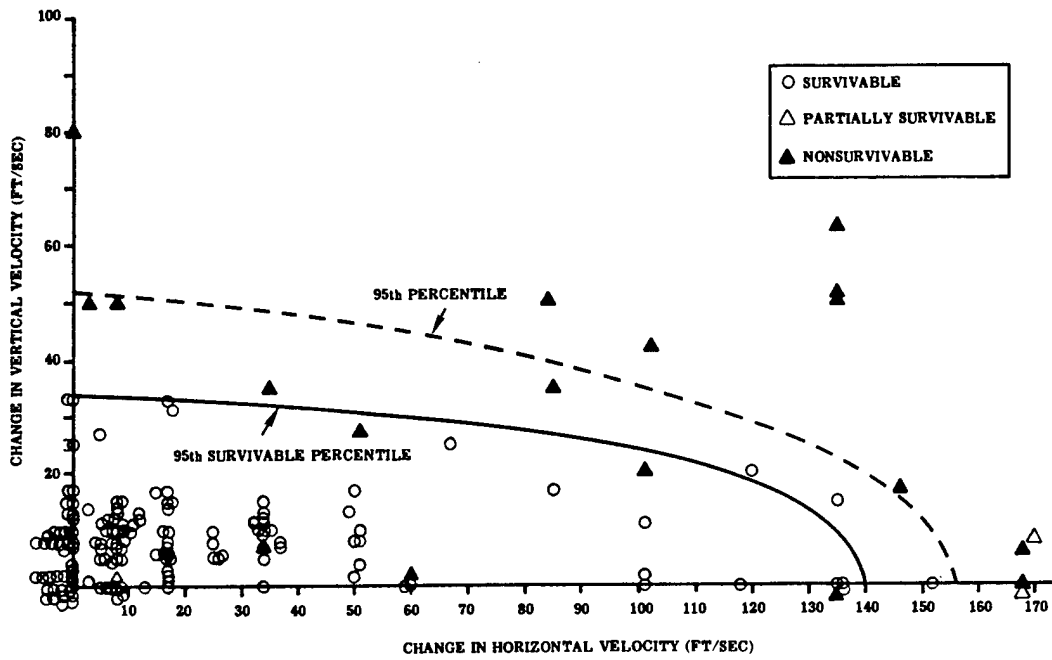


FIGURE 2. — Vertical and Horizontal Components of Impact Velocity Change (OH-58A)

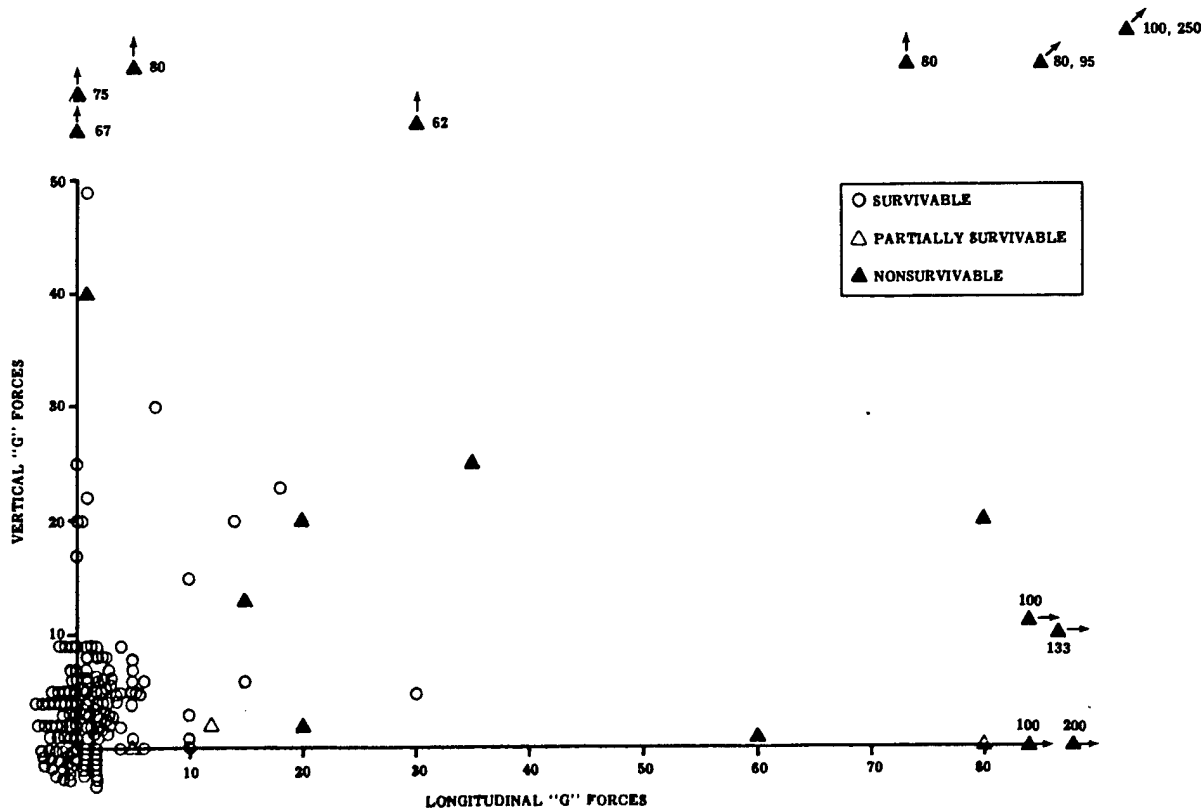


FIGURE 3. — Combined Vertical and Longitudinal "G" Force Components (OH-58A)

grouping around several "reasonable" points. This is the result of the estimating technique required and indicates higher inaccuracy regarding aircraft stopping distances and crash loadings than demonstrated for aircraft velocity change.

**Impact Kinematics.** The kinematics of the aircraft motion following initial ground impact influence occupant survivability by introducing additional crash hazards beyond the initial crash. The frequencies of occurrence of OH-58A impact kinematics which appeared to have the strongest influence on occupant survivability are shown in figure 4.

It should be noted that figure 4 depicts the frequency of occurrence of each impact kinematic as a percentage of *all* accidents. Relatively low

frequency occurrences (such as three percent for inverted impacts) cannot be ignored because of their high injury potential.

**Description of Terrain Struck.** The type of terrain at the point of major impact affects occupant survivability through its influence on aircraft stopping distance. The relative frequency of occurrence of important terrain characteristics in the OH-58A accidents studied is shown in figure 5.

**Frequency and Classification of Casualties.** The overall casualty classifications for the 383 occupants of the above accident aircraft are shown in table 2. A total of 144 of the 383 occupants (or 37.6 percent) suffered some degree of crash injury.

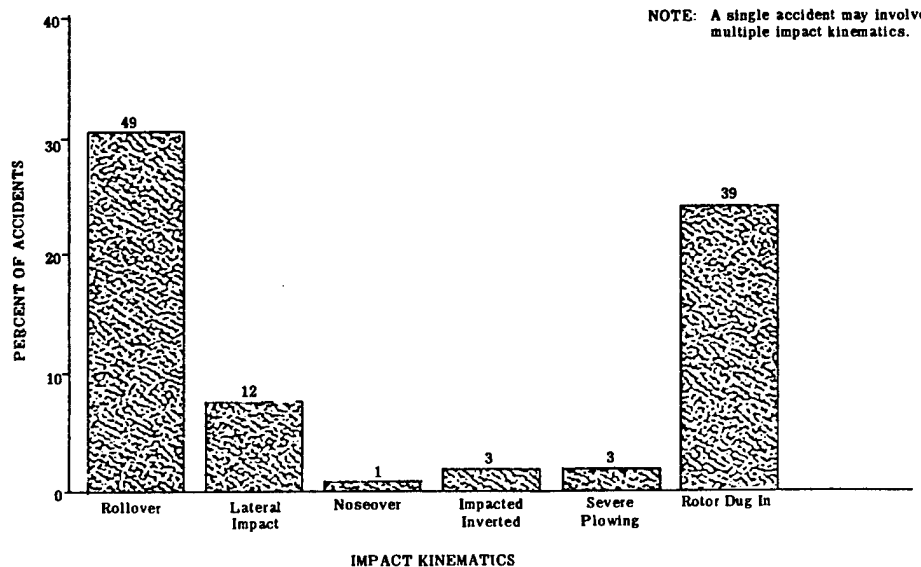


FIGURE 4.—Relative Frequency of OH-58A Impact Kinematics

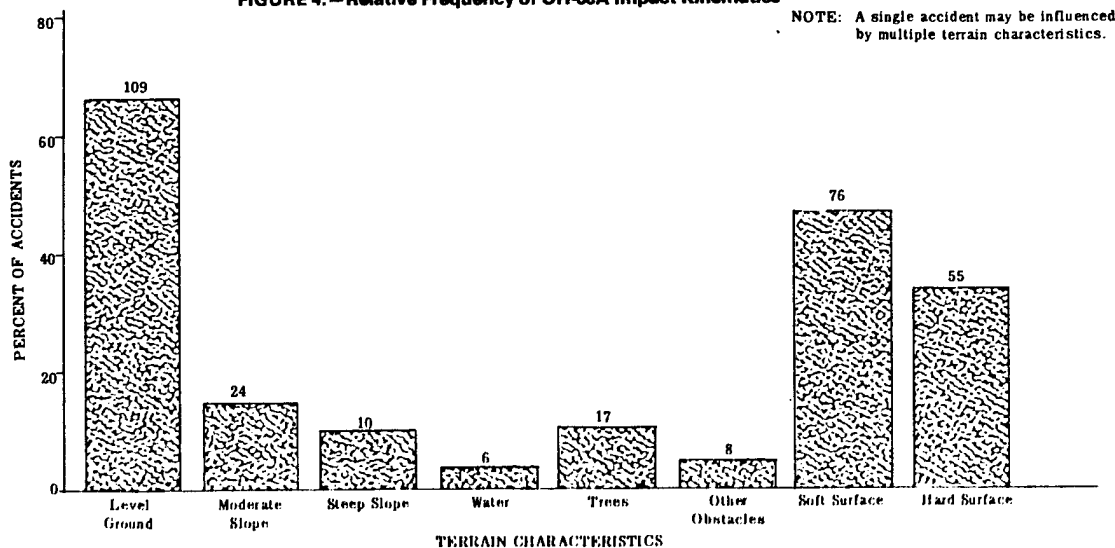


FIGURE 5.—Relative Frequency of OH-58A Accidents Involving Important Terrain Characteristics

**TABLE 2.—Frequency of OH-58A Casualties by Classification**

Classification	Frequency	Percent of All Casualties
None	239	62.4
Minor	60	15.7
Major	47	12.3
Fatal	37	9.7
Unknown/ Unclassified	0	0.0
<b>Total</b>	<b>383</b>	<b>100.0</b>

**Frequency of Injury by Severity.** The 144 casualties noted above experienced a total of 289 separate injuries. These were distributed by severity as shown in table 3. Almost half of all the injuries (48.8 percent) were serious enough to be classified as at least major.

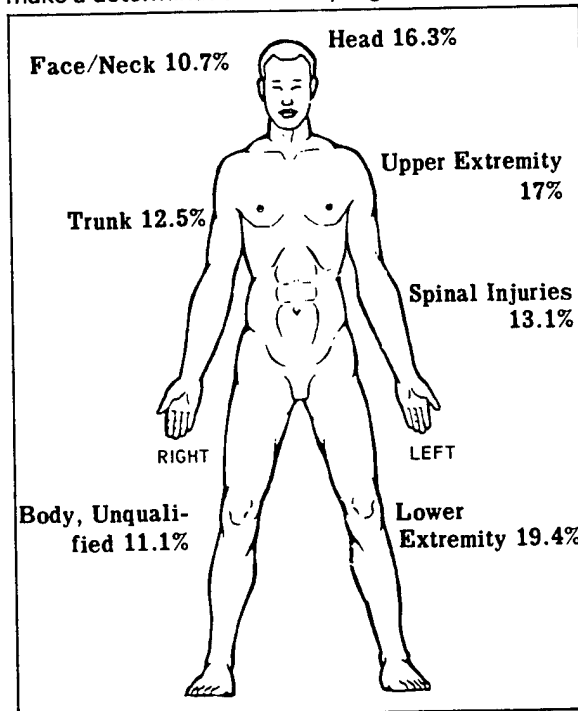
**TABLE 3.—Frequency of OH-58A Injury by Severity**

Injury Severity	Frequency	Percent of All Injuries
Minimal/Minor	148	51.2
Major	86	29.7
Critical	6	2.1
Fatal	49	17.0
Unclassified/ Unknown	0	0.0
<b>Total</b>	<b>289</b>	<b>100.0</b>

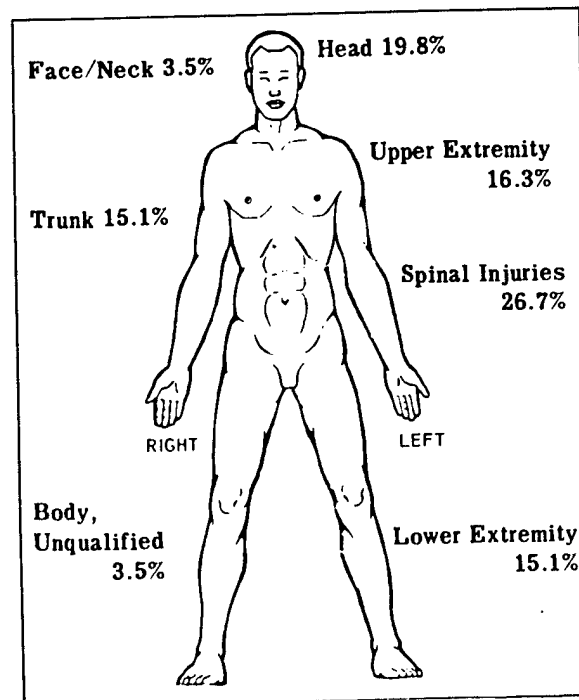
**Frequency of Injury by Location.** The body locations of the above crash injuries have a strong influence on determining the engineering solution to the associated injury cause factors. Figures 6 through 8 indicate the relative frequency of injury to the major body locations.

It should be noted from figure 6 that, considering all classifications, OH-58A crash injuries are relatively evenly distributed across all the major body regions; however, figure 7 shows that a major portion of all the major injuries were concentrated in the spinal region. Moreover, figure 8 shows that a major portion of the fatal and critical injuries were concentrated in the head. Figure 8 also shows that a large portion of the fatal and critical injuries could not be classified to any particular body region. Most of these injuries were casualties experiencing multiple extreme injuries in

severe, nonsurvivable impacts, in which the injuries would not be localized by body region. The remainder of these unclassified injuries were cases in which insufficient data was available to make a determination of body region involved.



**FIGURE 6.—Location of All Injuries (OH-58A)**



**FIGURE 7.—Location of Major Injuries (OH-58A)**

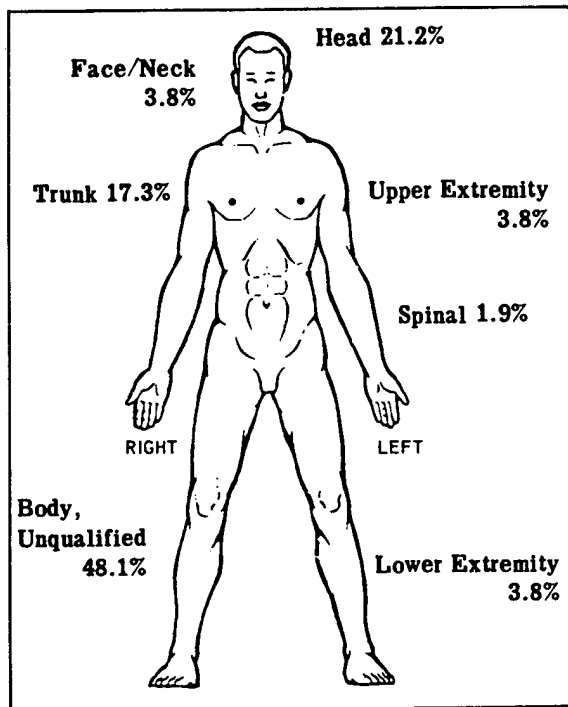


FIGURE 8. — Location of Fatal/Critical Injuries (OH-58A)

**Influence of Impact Conditions on Spinal Injury.** Figure 9 shows the relative frequency of back injuries (as a percentage of occupants exposed) versus impact vertical velocity change. Figure 9 indicates that significant numbers of back injuries do not occur in the OH-58A impacts involving vertical velocity changes less than 15 feet per second. However, the incidence of spinal injuries increases sharply in impacts above (an estimated) 20 feet per second vertical velocity change. It is in these impacts that the excessive number of all major injuries (localized to the spine as indicated in figure 7) begin to occur.

Points above 30 feet per second vertical velocity change have been deleted from figure 9 because increasing frequency of multiple extreme injuries above this value makes the recorded spinal injury data inaccurate and misleading.

The data indicates that the crash force attenuation, i.e., shock absorption, of the OH-58A aircraft and seat is inadequate for impacts exceeding 15 to 20 feet per second in vertical velocity change. It is interesting to note that the OH-58A skid gear design sink speed (no fuselage ground contact) is 12 feet per second. The fact that significant spinal injuries begin to occur at a vertical velocity only slightly above the gear design

limit indicates little shock absorption is provided by the fuselage and seats. A contributing factor is that, as discussed in reference 8, the anthropometric design of the seat and primary flight controls require many OH-58 aviators to adopt a seating position which forces flexion of the spine (i.e., the aviator must slouch). This reduces the tolerance of the aviator to vertical impacts and simultaneously increases the slack in his restraint system.

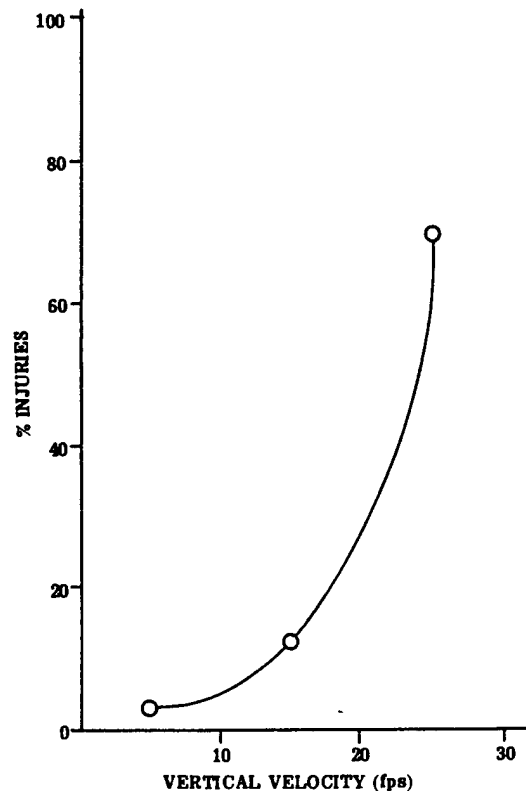


Figure 9.—Relative Frequency of Spinal Injuries Versus Change in Vertical Velocity (OH-58) as a Percentage of Occupants Exposed

**Frequency of Occurrence and Costs of Injury Mechanisms.** Figure 10 shows the frequency of occurrence and cost associated with the most prevalent crash injury mechanisms. All accidents regardless of the survivability and all injuries regardless of severity are included. The figure indicates that the injury mechanism which produced the largest frequency was "body struck structure" while the mechanism producing the largest cost was "body received excessive decelerative forces." The remaining mechanisms "body struck by external object," "body exposed to fire," and "body struck cyclic" produced lower frequencies and costs. The mechanism "body

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experienced multiple injury producing mechanisms" is not considered a preventable factor because it is generally indicative of severe, nonsurvivable impacts with multiple extreme injuries.

**Cause Factors Resulting in Injury Mechanism "Body Struck Structure."** As discussed above, the mechanism "body struck structure" resulted in the highest injury frequency. The cause factors which resulted in this mechanism are shown in figure 11. Figure 11 indicates that the most frequent cause factor resulting in this mechanism was simply flailing of extremities into the structure. Because these injuries are typically not fatal or critical, the cost associated with this cause factor was exceeded by the cost of other factors. The cause factor resulting in the next largest injury frequency was excessive collapse of the structure into the occupied area. The cause factor resulting in the largest injury cost was the main rotor penetration of occupiable space.

**Cause Factors Resulting in the Mechanism "Body Received Excessive Force."**

The cause factors which caused the injury mechanism "body received excessive decelerative force" are presented in figure 12. Of these, the largest frequency and costs are those associated with aircraft and seat allowing excessive loading of the occupant. The energy absorption capabilities of landing gear, airframe, seat (and in some cases the failure of the restraint system to maintain the occupant properly) failed to protect the occupant under these impact conditions.

**Most Significant Crash Hazards.** The combination of the above injury mechanisms and cause factors comprise the crash hazards identified through analysis of OH-58A aircraft accident data. A total of 20 crash hazards were identified for this aircraft type. Table 4 lists the hazards in decreasing order of significance (based on frequency, severity, and cost). The injury costs associated with each hazard were computed for a

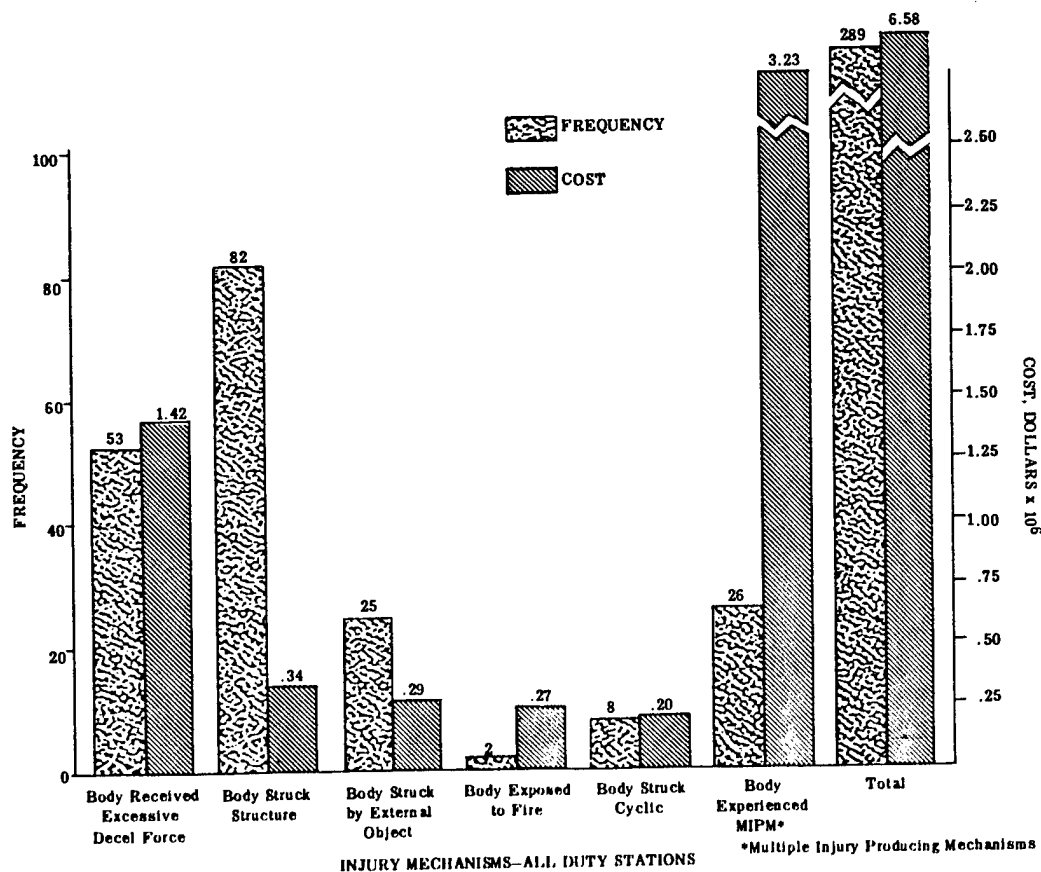


FIGURE 10.—Frequency and Cost of OH-58A Injury Mechanisms

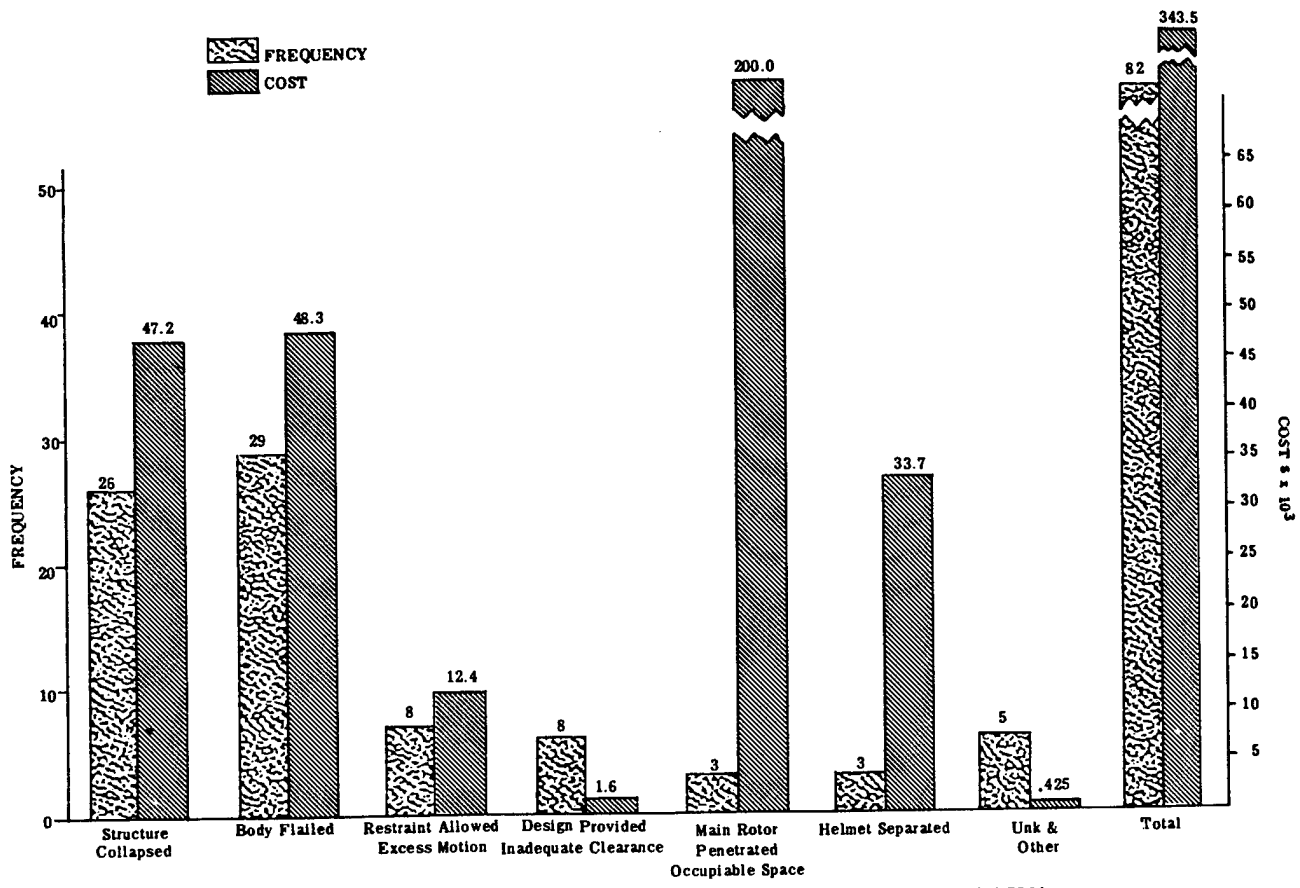


FIGURE 11. — Frequency and Cost of Cause Factors Resulting in Body Struck Structure (OH-58A)

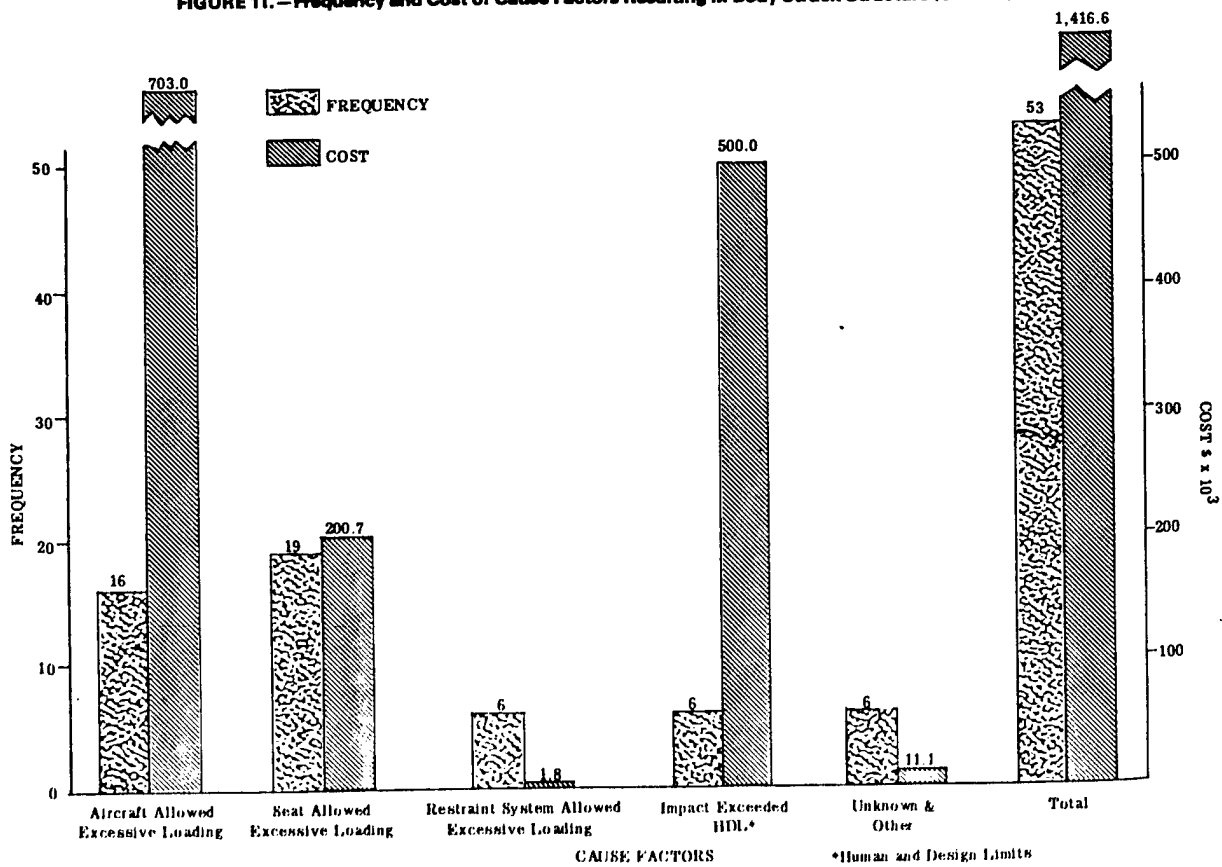


FIGURE 12. — Frequency and Cost of Cause Factors Resulting in "Body Received Excessive Decelerative Forces" (OH-58A)

**TABLE 4.—Rank Ordering of OH-58A Crash Hazards**

Hazard No.	Significance Group	Description	Frequency Index	Severity Index	Projected 20-Year Hazard Cost (FY 76\$)
<b>Hazards reasonably influenced by crashworthiness design:</b>					
1	2	Personnel received excessive decelerative load when seat and aircraft transmitted excessive force.	B	I	5,175,169
2	2	Personnel struck structure when structure collapsed.	B	I	663,079
3	2	Personnel struck by external objects when external objects entered occupiable space.	B	I	401,077
4	3	Personnel struck structure because restraint system failed.	C	I	1,462,184
5	3	Personnel struck by main rotor when main rotor entered occupiable space.	C	I	1,160,784
6	3	Personnel struck structure when body flailed.	B	II	204,776
7	4	Personnel exposed to fire when fuel tanks failed on impact.	D	I	963,472
8	4	Personnel thrown from aircraft when restraint system failed.	D	I	395,059
9	4	Personnel struck by transmission when transmission entered occupiable space.	D	I	358,612
10	4	Personnel struck structure when restraint system allowed excessive motion.	C	II	58,492
11	4	Personnel struck structure because design provided inadequate clearance.	C	II	6,537
12	5	Personnel injured by excessive restraint system loads.	D	II	24,756
13	5	Personnel struck by loose internal objects displaced by impact forces.	D	II	4,516
14	6	Body struck by helmet when helmet displaced.	D	III	574
15	6	Personnel struck by seat armor displaced by impact forces.	E	II	12,420
16	7	Personnel received excessive decelerative forces when body flailed.	E	III	1,058
17	7	Personnel struck structure when seat failed.	E	III	673
<b>Hazards not reasonably influenced by crashworthiness design:</b>					
18	2	Body experienced multiple injuries when impact exceeded design limits.	B	I	12,579,674
19	4	Other injury causes (unknown, unclassified, or unusual injuries).	D	I	223,715
20	4	Personnel injured when helmet separated due to unknown causes.	D	I	212,815

20-year period of aircraft operation, with the rates and types of accidents assumed the same as in the base study period (table 1). The fleet flying hour rate was calculated based on planning figures (obtained from the office of the Deputy Chief of Staff for Logistics, HQ DA) of 15 hours per aircraft per month. Fleet size was calculated based on an attrition rate of 10 aircraft per year. The hazards listed in table 4 are divided into two groups: those which are reasonably influenced by crashworthiness design and those which are not. This is done to focus on those hazards and injuries which are preventable. All of the hazards listed on the upper portion of table 4 are potentially preventable.

It should be noted that table 4 does not include costs associated with injuries which occurred in crashes in combat. Nor does it include costs due

to litigation by injured personnel or their families, whether directly against the Government or indirectly against the Government's contractors. These additional cost factors could substantially increase the hazard costs shown in table 4.

**Crashworthiness R&D Requirements for Current Aircraft.** The above rank-ordered listing of crash hazards was analyzed to identify pressing research, development, and product improvement requirements. Table 5 summarizes the hardware deficiencies which resulted in serious but preventable hazards in current aircraft. Research, development, and acquisition programs required to reduce these deficiencies are also suggested in table 5, along with the potential 20-year savings which would accrue if all of the associated injuries were prevented.

**TABLE 5.—Crashworthiness RD&A Requirements for OH-58A Aircraft**

Priority	Crashworthiness Deficiency	Hazards Resulting From This Deficiency	RD&A Requirement	Potential 20-Year Savings, FY 76\$
1	Aircraft and seats transmit intolerable vertical loads to occupants, resulting in the excessive spinal injuries depicted in Figure 9.	1	Perform feasibility study and preliminary design of optimum method of increasing vertical energy absorption. Evaluate mods to landing gear, airframe, and seats. Design criteria should be developed based on impact conditions contained herein.	\$5,176K
2	Occupant restraint system allows longitudinal and lateral movement of upper body on impact.	4, 6, 8, 10, 11	Develop and procure replacement crew restraint system providing more longitudinal and lateral restraint for upper body. Design goal should be to prevent injurious head contact with aircraft structure in impacts up to the 95th percentile survivable impact depicted in Figure 2.	\$2,125K
3	Main rotor displaces downward on impact and enters occupiable space.	5	Develop and procure method to prevent main rotor blade intrusion into crewstation. Design goal should be that main rotor blade will be prevented from entering occupiable space in blade impacts up to normal rotor rpm.	\$1,161K

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In addition to the above requirements, preventable thermal injuries due to fuel-fed postcrash fires in accident aircraft not equipped with a crashworthy fuel system made the completion of the fuel system retrofit program a high priority requirement. This program has been completed during the study period for OH-58A aircraft, and therefore this requirement is considered fulfilled for this aircraft type. The thermal casualties which occurred in the study period, however, underscore the requirement to complete the retrofit of all aircraft types.

The OH-58A crew restraint system was modified subsequent to the study period to strengthen the attachment of the lap belt to the aircraft (reference 9). Incorporation of this modification will reduce the frequency of restraint system failures and associated injuries.

**Additional R&D Requirements.** The results of the present analysis suggest that a more accurate system of determining the impact conditions in all Army aircraft accidents is required. Presently, these conditions (velocities, angles, and forces) are estimated by the accident investigation board based on witness statements and physical evidence such as aircraft and terrain damage. The inaccuracies in this method are evidenced by the fact that accurate estimates of the crash impact forces were impossible to obtain using information presently available. These data were seen to cluster around certain "typical, reasonable" values and precluded any valid estimate of their actual distribution (such as their 95th percentile

values). An onboard crash data recorder is required for proper analysis of the impact conditions against which crashworthiness improvements must be designed and evaluated. Such a system is included as a portion of the Accident Information Retrieval System (AIRS) which is under development of the Army's Applied Technology Laboratory (reference 10).

### CONCLUSIONS

Crashworthiness design deficiencies in OH-58A aircraft and the research necessary to remedy them have been identified based on a systematic analysis of aircraft accident reports.

It is concluded that the research, development, and acquisition programs of highest priority in improving the crash survivability of the OH-58A series aircraft are as follows:

- Improved vertical energy absorption in the aircraft structure, landing gear, and/or seat.
- Crewmember restraint system with improved upper torso restraint.
- Rollbar/main rotor blade deflector.

In addition, it is concluded that an onboard crash data recording system is necessary in all Army aircraft for accurate determination of future crashworthiness design criteria.

### RECOMMENDATIONS

- Crashworthiness improvements for OH-58 aircraft address each of the three high priority research requirements identified in table 5.
- Development of the Accident Information Retrieval System be expedited.

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## Appendix A

### Definitions

**Aircraft accident.** Damage which occurs to one or more aircraft while flight was intended. Damage as a direct result of hostile fire is not an accident but a combat loss.

**Crash force.** The maximum value of an assumed triangular crash pulse, determined at the aircraft center of gravity, which occurs during the major impact.

**Crash hazard.** A condition due to the design or configuration of an aircraft or life support equipment which may result in injuries to occupants in aircraft accidents.

**Crashworthiness.** The ability of a vehicle to sustain a crash impact and reduce occupant injury and hardware damage.

**Hazard frequency.** The frequency of occurrence of injuries resulting from a particular crash hazard.

**Hazard severity.** The severity of the worst credible injury resulting from a particular crash hazard.

**Hazard cost.** The sum of the costs of all injuries resulting from a particular crash hazard.

**Injury cause factor.** The design deficiency which caused a specific injury mechanism to occur.

**Injury classification.** A designation of the medical significance of all of the injuries incurred by a given casualty taken as a whole.

**Injury cost.** The economic effect on the operational readiness of the Army due to accidental injuries to servicemembers, as calculated according to reference 2.

**Injury mechanism.** The mechanical process through which a specific injury was determined to have occurred, i.e., "what happened."

**Injury severity.** A designation of the medical significance of a specific injury.

**Major impact.** That impact of the aircraft which results in the largest decelerative forces being transmitted to the aircraft and occupants.

**Survivable accident.** An accident in which the following statements are satisfied for at least one occupant aboard the aircraft:

a. The forces transmitted to the occupant through his seat and restraint system do not exceed the limits of human tolerance to abrupt accelerations.

b. The fuselage structural container maintains a livable volume around the occupant.

**Nonsurvivable accident.** An accident in which neither of the above statements is satisfied for all occupants aboard the aircraft.

**Partially survivable.** An accident in which both survivable and nonsurvivable occupant positions exist.

**Velocity change.** The change in velocity of the aircraft c.g. during the major impact.

Other terminology is as defined in reference 3.

# Appendix B

## Methodology for Identification and Ranking of Crash Hazards

(From Reference 1)

As used herein, a crash hazard consists of the combination of an injury location, its mechanism, and its associated cause factor. These hazards identified through the analysis of accident reports were rank-ordered according to their overall significance. The criteria which were used to rank the hazards were (1) the frequency of injuries resulting from the hazard, (2) the severity of these injuries, and (3) their total cost. For purposes of shorthand notation, these factors are termed the "hazard frequency," "hazard severity," and "hazard cost," even though the *result* of the hazard is the factor which is being evaluated and not the hazard itself.

The procedures used to rank the hazards consisted of two steps: First, the hazards were placed into groups of significance according to their frequency and severity. Next, the hazards within each significance group were ranked according to their cost. These hazards were considered in identifying urgent crashworthiness research and development programs for both current and future helicopters.

**Ranking According to Frequency.** Each hazard was evaluated according to the frequency of occurrence of the resulting injuries as shown in table B-1. The format and rationale for this frequency ranking were modeled after reference 11.

**TABLE B-1.—Crash Hazard Frequency Ranking**

Frequency Index	Descriptive Nomenclature	Mathematical Definition
A	Frequent	$0.5 < f^*$
B	Reasonably probable	$0.1 < f \leq 0.5$
C	Occasional	$0.05 < f \leq 0.1$
D	Remote	$0.01 < f \leq 0.05$
E	Improbable	$f \leq 0.01$

\*f is defined as the relative frequency of injury occurrence and is calculated as

$$f = \frac{\text{Frequency of occurrence of resulting injuries}}{\text{Number of accidents studied}}$$

**Ranking According to Severity.** Each crash hazard was evaluated relative to the severity of the

resulting injuries as shown in table B-2. The rationale and format for this severity ranking procedure were taken from reference 11.

**Table B-2.—Crash Hazard Severity Ranking**

Severity Index	Descriptive Nomenclature	Definition
I	Life-threatening	Results** in fatal or critical injury
II	Serious	Results in major injury
III	Marginal	Results in minor injury
IV	Negligible	Results in no more than minimal injuries

\*\*Worst credible result

**Overall Ranking of Crash Hazards.** The results of evaluating each crash hazard according to its frequency and severity as described above were used together to place the hazards into overall significance groups. The frequency and severity rankings of each hazard were weighted equally in this process. Table B-3 indicates how all hazards were placed into one of eight groups as determined by the combination of frequency and severity indices.

**TABLE B-3.—Hazard Significance Groups Based on Frequency & Severity Indices**

Significance Group	Frequency Index-Severity Index
1	A.I
2	A.II, B.I
3	A.III, B.II, C.I
4	A.IV, B.III, C.II, D.I
5	B.IV, C.III, D.II, E.I
6	C.IV, D.III, E.II
7	D.IV, E.III
8	E.IV

After placing all hazards into significance groups, the crash hazards *within* each group were then rank-ordered according to the cost of the resulting injuries. The rank-ordered list which resulted comprises a "totem pole" of the most serious crash hazards.

## **Appendix C**

### **Participants in Study Group**

The analysis contained herein is the result of the efforts of a study group chaired by USASC. Participants are listed below:

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