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**ANALYSIS OF U.S. ARMY AVIATION
MISHAP INJURY PATTERNS
(Reprint)**

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**U.S. ARMY AEROMEDICAL RESEARCH LABORATORY
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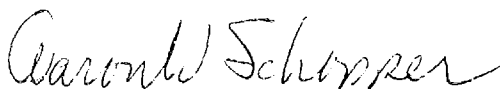
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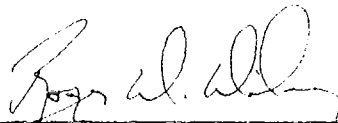
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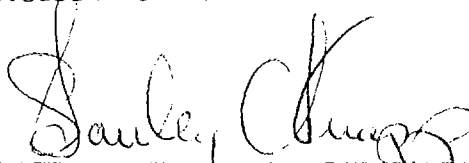


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SUMMARY

Recent advances in US Army procedures for the identification and reporting of personnel injuries resulting from aircraft mishaps are reviewed. Mishap injury data requirements based on the needs of retrospective and prospective analyses are discussed. The requirement for these analyses to support engineering management decisions that will implement remedial programs to correct identified crashworthiness deficiencies is discussed. This paper summarizes the US Army process for gathering aviation mishap injury data, describes modifications to procedures and codes for recording injury data, and provides examples of use of the data resulting in fleet-wide improvement programs.

INTRODUCTION

Since the earliest days of flight, it has been an inescapable fact that aviation mishaps will occur in spite of all efforts to the contrary. This statement is made not in an attempt to detract from the value of mishap prevention but to point out that man is an inherently fallible creature, and he has endowed the equipment and the systems that he develops with the same fallibility. Efforts toward mishap prevention have reduced the US Army aviation mishap rate considerably over the last decade; however, this rate appears to be plateauing toward a relatively constant value (Figure 1). Efforts toward reducing this rate must be continued, but realistically one must assume that the goal of a zero accident rate is not achievable. Furthermore, it is inevitable that crashes will occur as a result of enemy action in a combat environment. Consequently, to minimize these costs both in terms of materiel and personnel losses, it is vital to design crashworthy aircraft and effective life support equipment. Crashworthy designs are, in part, achieved through an understanding of injury mechanisms identified through mishap investigations.

Numerous papers over the past 25 years have reported the incidence and distribution of injuries occurring in US Army aviation mishaps (1,2,3,5,6). Probably the most salient feature of this quarter century of tracking injuries is that the distribution and type of injuries have changed very little, with one important exception. Thermal injury as a cause of death in survivable accidents has been reduced from 41% in 1969 (3) to essentially zero today (7,9) due to the introduction of crashworthy fuel systems in most US Army helicopters in the early 1970's. This rather dramatic achievement occurred through a process of identification and documentation of the problem (mishap investigations) which led to a practical engineering solution. Implementation of a "fix" normally requires a cost justification (i.e., cost analysis), but in the case of thermal injury the nature and severity of the problem was so great that little cost analysis was required.

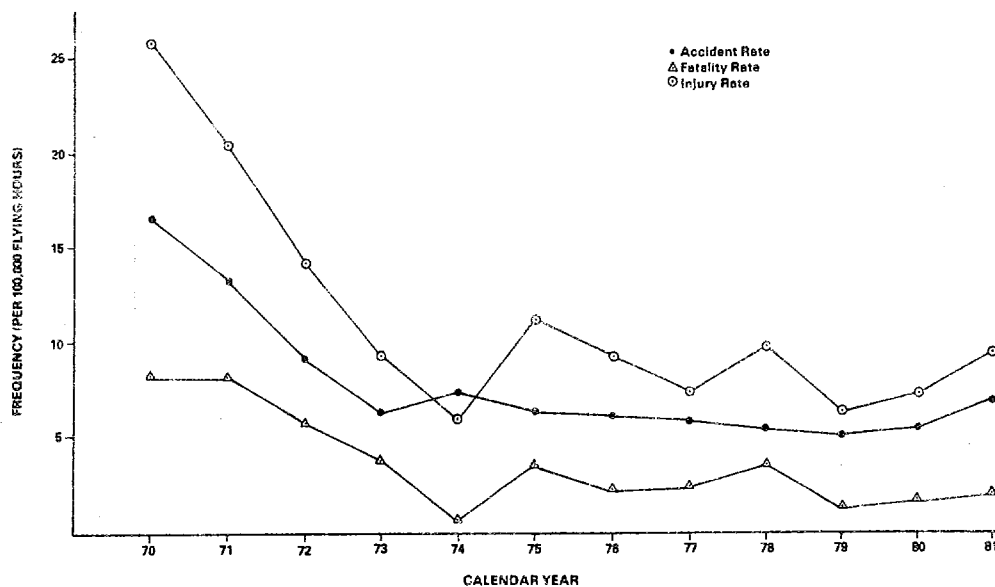


FIGURE 1--US ARMY AVIATION MISHAP EXPERIENCE (CY 1970-CY 1981)

Although this example demonstrates the general method of approaching injury prevention, thermal injury was a rather obvious problem with fairly readily obtainable solutions. Prevention of the most prevalent areas of injury, namely to the head, spine, and extremities (6) is proving to be a far more elusive objective. Solutions to these problems are requiring considerably more detailed and accurate data than has been collected in the past, and the cost effectiveness of proposed solutions must now be readily demonstrable in order to justify their implementation. Identification of mechanisms of injury and their relationship to life support equipment (LSE), i.e., seats, restraints, helmets, have become primary concerns in the quest for means of preventing injury. Furthermore, since this is basically an epidemiological problem requiring the compilation and analysis of relatively large volumes of data, the data should be readily reduced to a form that can be stored and processed by computer. Recognizing these problems, the US Army Safety Center (USASC), together with the Armed Forces Institute of Pathology (AFIP) and the US Army Aeromedical Research Laboratory (USAARL), has developed a system of aircraft mishap injury investigation and analysis that will be described in this paper.

CRASH INJURY IDENTIFICATION AND REPORTING

OVERALL MISHAP INVESTIGATION PROCESS

Since 1978, the US Army has used a system of Centralized Mishap Investigation (CMI) wherein USASC provides investigators for the majority of major aviation mishaps. The USASC maintains a number of investigation teams; each consisting of three members (board president, air safety specialist, and recorder). The team serves as the core of the investigation board and draws on local expertise and resources to conduct the investigation. This system of providing a highly trained and experienced team of investigators to direct the investigation of most major mishaps has improved the overall technical quality of investigations by insuring a thorough and standardized approach and uniform reporting methods.

In 1979, through an agreement between USASC and AFIP, AFIP began providing, on a time available basis, an aerospace pathologist to perform the autopsies on fatalities in US Army mishaps. Since the inception of the program, AFIP has performed all but a few of the autopsies. This has vastly improved the quality of necropsy data because these aerospace pathologists are well trained in forensic methods, and they are particularly attuned to the determination of injury mechanisms derived not only through analysis performed at the autopsy table but also through correlation with the kinematics of the crash and damage to the aircraft and LSE. Before 1979, autopsies were performed by local hospital pathologists or medical examiners who may or may not have possessed the necessary interest or training to perform a comparable quality investigation. The flight surgeon assigned to the mishap investigation board assists the aerospace pathologist in his investigation and does a similar injury investigation on all individuals who survived the mishap.

As an adjunct to the onsite injury investigation provided by the investigation board and AFIP, USAARL has established the Aviation Life Support Equipment Retrieval Program (ALSERP) which, by Army regulation, requires that all items of aviation LSE "in any way implicated in the cause or prevention of injury" be sent to USAARL for detailed analysis (8). This program seeks to precisely define the effectiveness of LSE involved in mishaps by correlating damage to the equipment with injuries (or lack of injuries) and other data derived from the field investigation of that particular mishap. This data is coded and stored in a computer for later use in identifying trends or consistent failure modes for various items of LSE. Once problems with a particular piece of equipment are identified, recommendations for changes in design criteria can be made. The major accomplishment of this program to date has been the identification of various failure modes of the current US Army aviation helmet which has, in part, led to the drafting of new aviation helmet design criteria (4). This program is also being used to monitor the functioning of energy-absorbing seat designs which are currently being introduced to the field.

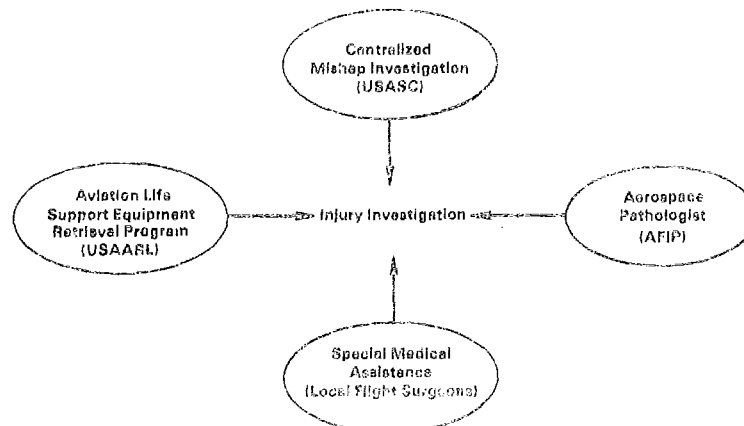


FIGURE 2--INJURY INVESTIGATION

As shown in Figure 2, this combination of centralized mishap investigation, centralized postmortem examination of fatalities, and systematic analysis of retrieved LSE has vastly improved the depth and quality of injury investigation in US Army aviation mishaps through standardization of procedures for data collection and by using experienced and highly trained individuals in key positions.

AVIATION CRASH INJURY REPORTING SYSTEM

The aviation mishap investigation process described above provides the overall framework for the identification and recording of aircraft crash injury information. A modified injury coding system has been developed to operate within this framework and provide the necessary medical, engineering, and management information to support required remedies. Completed in 1981, the format and structure of this code are described below.

Overall Format of Code

The proposed code is structured to include the four data fields shown in Table I below:

Each one of the data fields will be described separately, after which an example will be provided which demonstrates use of all the data fields together. The proposed reporting system provides that each injury data field will be reported for each separate and distinct injury cause factor as defined below.

TABLE I
OVERALL STRUCTURE OF PROPOSED US ARMY AVIATION MISHAP INJURY CODE

Data Field Number	Nomenclature	Information Provided	Number of Data Elements
1	Identifier	Medical description of trauma	5
2	Mechanism	Physical process of injury occurrence	2
3	Deficiency	Underlying cause(s)	3
4	Cost	Economic impact of lost time, etc.	1

Injury Identifier

The trauma incurred by each occupant is reported in terms of a medical description of the injuries and their individual severities. Injuries suffered by those requiring less than first aid are reported as "none." For others, the injury characteristics shown in Table II are reported for each distinct injury.

Actual codes used for each of these data elements are available from USASC. A major departure from previous practice is the proposed identification of injury location in terms of the combination of an overall major body part, its aspect, and the system involved. This is in contrast to the common practice of a specific anatomical identification. This departure greatly enhances the usefulness of the coded data for identification of remedial measures for most injury types. For certain exceptions,

TABLE II
INJURY IDENTIFIER DATA ELEMENTS

Data Element	Nomenclature
1	Location of injury (major body region)
2	Aspect(s) of injured region affected
3	Type of lesion
4	Body system involved
5	Injury severity (established in accordance with (1))

provisions are made for more specific injury location identification. At this writing, there are two exceptions anticipated--the specific anatomical part will be reported for (1) spinal injuries, and (2) for head (skull) injuries. This is necessary in the two cases listed in order to determine the specific remedial measures needed.

Injury Mechanism

The mechanism of injury occurrence is used to describe the physical process through which each injury occurred. The injury mechanism is constructed in a subject-verb-qualifier format. Two data elements are used--the mechanism action ("verb") and the mechanism qualifier. The injury location (body part) provides the subject. Thus, a simple sentence is formed from standardized codes to describe the injury mechanism such as spine (L-1) "received excessive vertical force." Multi-year studies of aviation injury patterns were used as the basis for selection of the particular mechanisms to be included in the lists of codes. An attempt was made to balance the requirement for mechanism specificity with needs of engineering analysis. An overly detailed code hampers the identification of corrective actions.

Injury Cause Factor

The injury cause factor is identified as that underlying deficiency (or deficiencies) which permitted or caused the mechanism to occur. Injury causes are identified primarily in terms of hazards associated with the design of the aircraft or life support equipment (such as "seat allowed excessive loading"). Operational injury causes are also included such as "failed to use restraint system."

The injury cause factor is constructed in a subject-verb qualifier format in a manner similar to that used for the mechanism above. Thus, the injury cause is formed in a simple sentence from standardized codes.

Injury Cost

US Army Regulation 385-40 (10) establishes the economic impact of various injury severity levels based on lost workdays, restrictions from duty, and other similar considerations. Estimates of the cost of each individual injury suffered by each casualty are computed according to these figures and projections by the flight surgeon regarding the prognosis for recovery. Injury costs are calculated by USASC personnel based on data provided by the field investigation. The technique for calculating injury cost insures that each distinct injury is "weighted" according to its individual severity. The sum for any casualty of the weighted costs for all injuries is equal to the overall cost for that individual.

Hypothetical Example of Use of The Injury Code

The above components of the injury code are established for each distinct injury suffered by each injured occupant. "Distinct" injuries are defined as those (a) with different cause factors, or (b) occurring to different major body regions. This information provides a description of the injuries, causes, and costs in a format and level of detail which facilitates analysis of critical trends. Thus, an injury code such as the hypothetical example shown in Table III below is established for each casualty.

TABLE III

HYPOTHETICAL EXAMPLE OF USE OF INJURY CODE FOR CASUALTY SUFFERING MAJOR INJURIES

INJURY NUMBER	INJURY DESCRIPTION					MECHANISM		CAUSE FACTOR			Injury Cost
	Location	Aspect	Type	System	Severity	Action	Qualifier	Subject	Action	Qualifier	
1	Spine, LI	Inferior	Fracture, comp	Skeletal	Major	Received	Excessive Decelerative Force	Seat	Allowed	Excessive Loading	\$45,405
2	Face	Anterior	Laceration	Skin	Major	Struck	Gunsight	Design	Provided	Inadequate Clearance	\$4,541
3	Hand	Right	Contusion	Skin	Minor	Struck	Structure	Extremities	Placed	On Impact	\$54

Total = \$50,000

DEVELOPMENT STATUS OF INJURY CODE

Initial development of the proposed injury reporting and analysis system was completed in early 1981. This code has been partially tested in retrospective analyses of Army aircraft mishap reports performed by USASC with assistance of other Army agencies. In these analyses, the injury code was demonstrated to facilitate the identification and ranking of crash hazards in helicopter designs, as discussed below. Other retrospective analyses, performed by USAARL, of specific head and spine injury

patterns indicated that the initial code lacked sufficient specificity in these two body regions, and the code has been modified accordingly. Evaluations have indicated that the proposed code requires more injury data than the previous system but that the data should be generally available within a mishap investigation.

Results indicate the code provides detailed information regarding injury mechanisms, causes, and costs. This information permits critical cause factors to be rank ordered according to the severity of their effect over selected time periods. This data provides vital management information regarding the need for remedial programs. In addition, the injury causes are described in a format and terminology which facilitates engineering solutions.

CRASH HAZARD ANALYSES

RETROSPECTIVE ANALYSES

Two levels of retrospective analyses of crash injury have been performed by the US Army. The first used the coding system described above to identify crash hazards in US Army aircraft. It was envisioned that a primary output of this effort would be an improved direction for crashworthiness research and development including the identification of follow-on research required to define specific design criteria changes necessary to reduce the identified hazards in current and future aircraft and LSE.

Analyses of this type have been completed for three types of Army aircraft; a medium lift cargo helicopter, an observation helicopter, and an attack helicopter (10,11,13). An analysis of a utility helicopter is ongoing and is scheduled for completion during the coming calendar year. The most significant results of one of the crash hazard analyses are discussed below. Emphasis will be placed here on those crash hazards associated with excessive linear acceleration. Supportive information, such as crash impact signatures, will also be provided and related to the injury causes.

Components of Change in Impact Velocity

Figure 3 shows the longitudinal and vertical components of the change in velocity of the aircraft center of gravity during its major impact for each of the accidents studied. The resulting impact survivability is indicated.

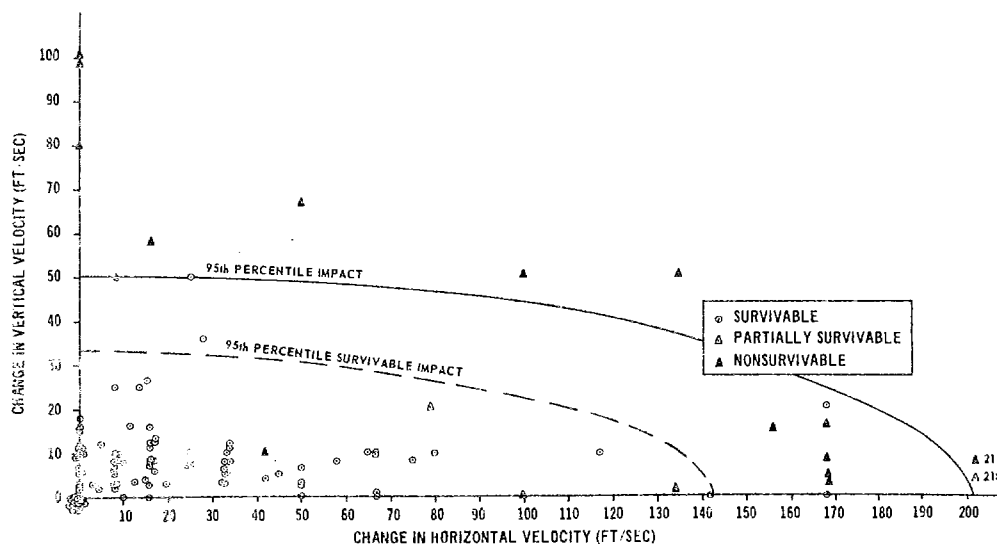


FIGURE 3--VERTICAL AND HORIZONTAL COMPONENTS OF IMPACT VELOCITY CHANGE

Estimated curves for the 95th percentile impact and for the 95th percentile survivable impact are superimposed on the individual data points. The 95th percentile survivable impact curves indicate a "design space" for improvements within the existing aircraft design. The 95th percentile impact is analogous information which may be useful for design and evaluation of crashworthiness features in future helicopters of similar type. This distinction is made because the strength and crushability of the existing airframe forming the "container" for the occupants limit the improvements which can be reasonably proposed for the current aircraft. However, for new aircraft designs, this limitation is not as severe due to potential improvements in the container itself. Thus, crashworthiness improvements for future helicopters should be based on what impacts are expected (such as the 95th percentile impact curve) and not on what impacts were survivable in current aircraft (the 95th percentile survivable impact curve).

Influence of Impact Conditions on Injury

The strongest influence of impact conditions on injuries was the relationship between vertical velocity change and spinal injuries. Figure 4 depicts the relative frequency of back injuries versus impact vertical velocity change. This data indicates that significant numbers of back injuries occur even in impacts of less than 20 feet per second vertical velocity change. Analysis of these individual cases revealed other factors had significant influence on these low impact cases. These other influences included the longitudinal and lateral components of the impact velocity and the occupant's seating position at the time of impact. However, the strongest influence is shown to be the vertical velocity change. Increasing proportions of all occupants receive spinal injuries as impact exceeds the reserve energy sink speed of the aircraft's landing gear (8 feet per second). These results indicate that ground impact loads are transmitted with little reduction through the fuselage and seat to the occupants.

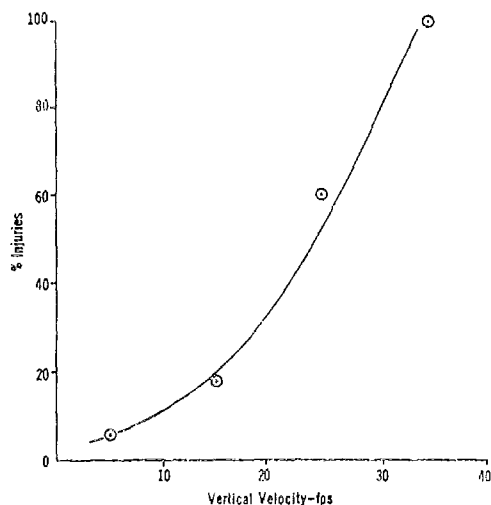


FIGURE 4--RELATIVE FREQUENCY OF SPINAL INJURIES VERSUS CHANGE IN VERTICAL VELOCITY

Figure 5 indicates the relative frequency of spinal injuries versus the vertical component of the peak impact forces (calculated at the center of gravity). Again, this data indicates significant numbers of back injuries occur in relatively mild vertical impacts. This data supports the conclusion that other factors (such as seating posture) have significant influences on spinal injury in even very low vertical impacts (such as less than 10 G's peak). This is important because most spinal injury models consider only the vertical impact component. In addition, this data supports the conclusion that after landing gear collapse, ground impact loads are transmitted directly with little attenuation to the occupants. This lack of energy absorption by the airframe and seat results in nearly 50% of all occupants receiving spinal injuries at peak crash loads of 15 G.

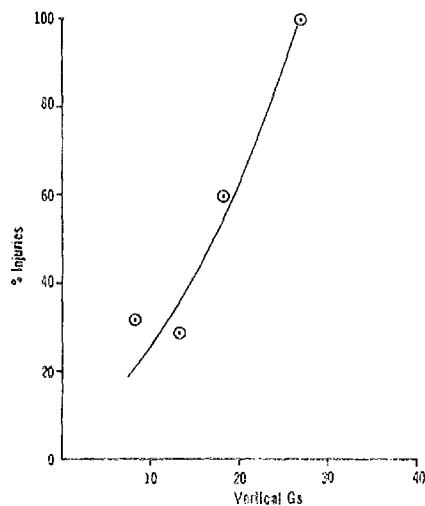


FIGURE 5--RELATIVE FREQUENCY OF SPINAL INJURIES VERSUS VERTICAL FORCE

Figure 6 depicts the frequency of occurrence and cost associated with the most prevalent crash injury mechanisms identified for the aircraft study. All accidents, regardless of survivability, and all injuries, regardless of severity, are included in Figure 6. A breakdown of the more significant injury mechanisms by underlying cause factor is discussed below. Figure 6 indicates that the most frequent injury mechanism was determined to be "body struck structure" while the mechanism resulting in the largest injury cost was "body received excessive decelerative force." After these two, the mechanisms of "body struck by external object" and "body exposed to fire" produced the next largest frequency and cost of injuries.

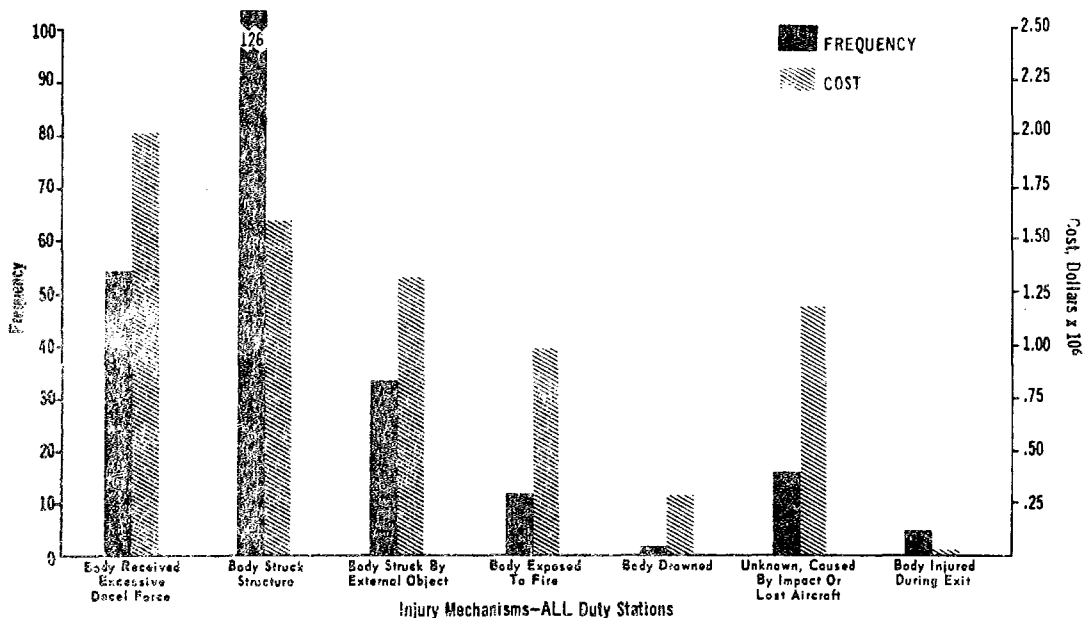


FIGURE 6--FREQUENCY AND COST OF INJURY MECHANISMS

Cause Factors Producing the Mechanism "Body Received Excess Force"

The engineering factors which caused the 55 instances of the mechanism "body received excessive decelerative force" are shown in Figure 7. This data indicates that a large majority of the instances and the associated costs of these injuries were caused by the airframe and seat allowing excessive loading of the occupant, i.e., during the major impact the aircraft and seat transmitted peak forces to the occupant which were beyond human tolerance. The energy absorption of the landing gear, airframe, and seat failed to protect these occupants.

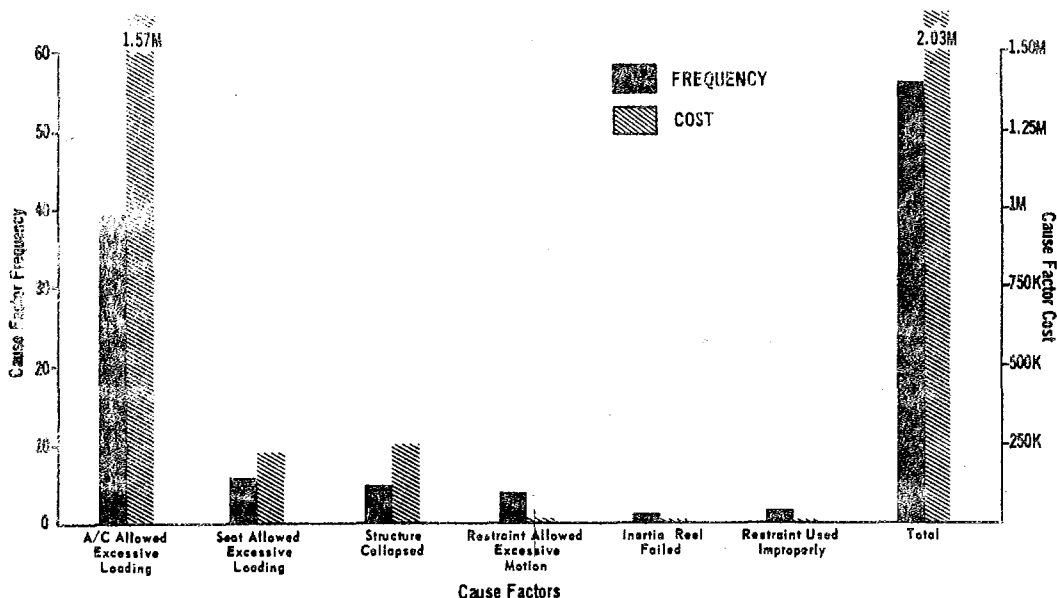


FIGURE 7--FREQUENCY AND COST OF CAUSE FACTORS RESULTING IN "BODY RECEIVED EXCESSIVE DECELERATION FORCE"

Identification of Crash Hazards

Using a technique discussed in a previous report (13), the combination of the above injury mechanisms and cause factors, frequency, severity, and cost was analyzed to identify the critical crash hazards for this type aircraft. The most significant or highest ranking crash hazard identified was the hazard "body received excessive decelerative force when the aircraft and/or seat allowed excessive loading." As stated above, the energy absorption capability of the landing gear, airframe, and seat failed to protect the occupants. Because any change to the strength and crushability of the airframe and landing gear would require a major modification or redesign, it would not be feasible to effect a change to these systems. Changes would, therefore, concentrate on the seat. Figure 8 depicts the resulting deficiency and the associated 20-year potential cost reduction.

<p>Crew seats transmit intolerable vertical loads to occupants and separate from aircraft, resulting in the spinal injury incidence vs. vertical impact severity depicted in figures 4 and 5.</p>	<p>Develop and procure replacement crew seats which will attenuate vertical loading on occupant to tolerable level. The seat design goal should be requirements of MIL-S-88055. Tradeoff studies are required to determine the degree of protection consistent with cost, weight and space constraints.</p>	<p>\$8,999,218</p>
<p>DEFICIENCY</p>	<p>CORRECTIVE ACTION</p>	<p>POTENTIAL 20 YR SAVINGS</p>

FIGURE 8--PRIORITY CRASHWORTHINESS NEED (EXAMPLE)

It should be noted that a modified seat cannot be easily designed to absorb sufficient energy for all impact levels shown in Figure 7. It also would not be cost effective because the seat survivability would not be compatible with the survivability limits of the airframe. It, therefore, becomes necessary to optimize the seat providing the maximum protection consistent with cost, weight, space constraints, and the existing airframe survivability limits. The results of this analysis provided sufficient rationale for the initiation and substantiation of an Army program to develop such an optimized seat as will be discussed later.

Returning to the overall types of crash hazard analyses, the second level of analysis was initiated by USAARI and is a more specific analysis of areas of concern identified by the first level analysis. A goal of this type analysis is to refine current criteria for protective hardware for specific body areas and provide a beneficial extension of the Aviation Life Support Equipment Retrieval Program. A study of head, face, and neck injuries in all recent US Army aviation mishaps has been completed and, as mentioned above, contributed to the identification of specific impact hazards and recommendations for changes in helmet design criteria (4) and unpublished data). Currently, a study of observation helicopter mishaps is in progress and is focusing on specific requirements to reduce injuries to the spine. A major emphasis of this study is to estimate the annual dollar cost of these injuries since approval of any retrofit program to improve seating in this helicopter will depend on an advantageous cost-benefit analysis.

PROSPECTIVE STUDIES

In an attempt to further improve the quality of injury data collected from mishaps, USAARI has initiated a program to study selected types of injuries in a prospective manner. This program is being developed in order to define codes of injury as precisely as possible in areas where it is believed the best possibilities for LSE and general crashworthiness improvements lie. Currently, this program is focusing on injuries to the head and the spine. This is based on the fact that these two areas encompass over a third of all injuries sustained in US Army aviation mishaps (6) and because of emphasis in the US Army on production of a new integrated flight helmet and the introduction of energy-absorbing seat designs.

Through systematic coordination with USACC, USAARI is informed of all mishaps involving injury, usually within 24 hours of the mishap. If injuries occur in one of the specific areas of interest, the flight surgeon assigned to the investigation is contacted and requested to provide detailed medical information (admission history and physical, photographs of injury, specific measurements of external injury, pertinent laboratory data, radiographs, and reports) as well as all pertinent LSE for analysis. Suggestions may also be made for obtaining any additional onsite data required. This field data is then analyzed by a team of specialists to determine the mechanisms of injury as accurately as possible. An assessment is also made as to practical means of preventing the injury. In this manner, crucial medical information can be collected and analyzed during the first few days after a mishap, and any additional information required can then be sought while it is still available. This program rarely requires

that USAARL send an individual to the scene of a mishap, but that capability exists and is used on occasion when the situation warrants. Medical information gained from these studies is provided to USASC and incorporated into the injury data reporting system previously discussed. Proposals have been made to give this program regulatory authority by revising appropriate regulations.

Since these prospective studies are just beginning, their full impact is yet to be determined. However, this method was recently used during the investigation of a UH-60A Black Hawk mishap wherein a specialized team was sent to the mishap site to assist in the injury investigation. As a result of this investigation, valuable information on the functioning of the energy-absorbing seats installed in this helicopter was collected and certain actual and potential failure modes were identified. Continued detailed investigations will be required to assemble the necessary data to optimize these energy absorbing seat designs.

REMEDIES RESULTING FROM USE OF CRASH DATA

The crash injury reporting system discussed here was developed with the objective of not only identifying hazards, as discussed above, but also providing appropriate justification of needed remedial actions. The current austere funding environment makes the conservation of US Army personnel assets more important, but it also reduces the resources available to aid in this conservation. Any program to improve the crash survivability of Army aircraft must compete for funding with all other programs. Priorities of all funded programs are generally established based on their impacts in the areas of cost and operational effectiveness. Thus, the crash injury reporting system is designed to provide output in these management terms. It must be pointed out here that analysis or discussion of the need for eliminating or minimizing a particular hazard to human life would be meaningless based solely on economics. For example, the basic need for aircraft crashworthiness cannot be analyzed adequately on the basis of the economics of crash injury alone.

However, assuming that a decision has been made that a particular hazard is to be controlled, then the next stage in the process regards the selection of the optimum method and hardware for actually doing the job. This is the point where the economics of personnel injury, i.e., cost effectiveness, should enter the decision process. This is due to the fact that the maximum overall reduction in hazard level is desired, but the resources available are usually limited.

The concept of cost-effectiveness can be readily used here to determine the optimum system configuration(s) by spotlighting that system which will provide the greatest relative benefits per dollar of expenditure. The emphasis here is on relative benefits since an absolute, complete value for the monetary advantages of a particular change cannot be calculated whenever human life is involved. These advantages are known only relative to those of alternate system configurations. Thus, the injury reporting system discussed here was designed to provide injury cost data which could be used to either substantiate the need for a remedial action or select an optimum remedy from a set of available alternatives.

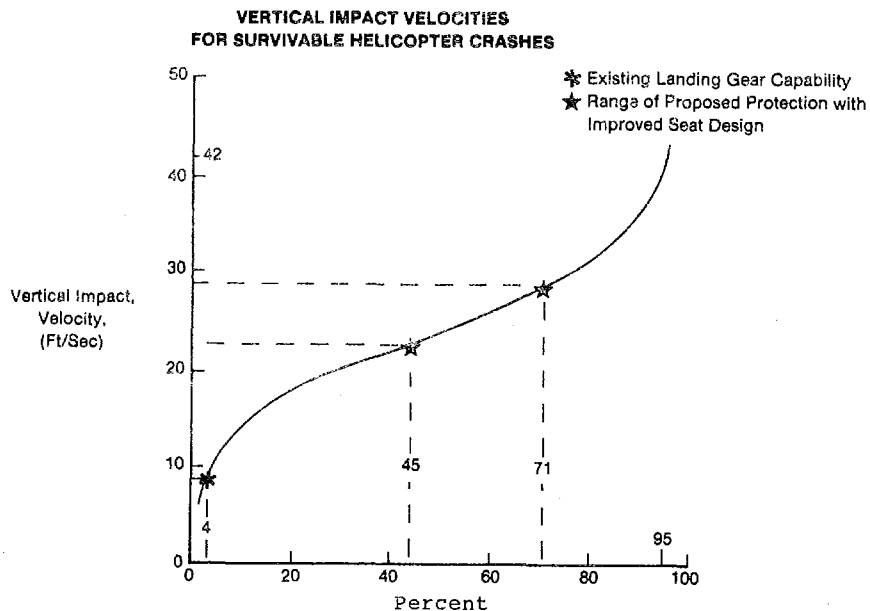


FIGURE 9--CUMULATIVE FREQUENCY OF OCCURRENCE

The identification and substantiation of the hazard regarding excessive vertical deceleration force transmitted to the crewmembers of the Army helicopter discussed above is instructive. As shown, this hazard was identified as the most critical crashworthiness problem in that aircraft. Equally important, the results of this analysis provided substantiating data for the justification of a "fix" in the form of the costs of the resulting injuries. Based partially on this information, an Army product improvement program has been initiated to address this aircraft/seat deficiency. The goal of this program is to enhance the survivability of this aircraft by incorporation of crashworthiness and vulnerability reduction design features. Included is an energy-absorbing seat which provides the maximum vertical stroke feasible within the constraints of the aircraft design. This seat will provide protection for a substantial proportion of survivable impact conditions. Figure 9 indicates a distribution of vertical velocity changes which is generally accepted to describe survivable impacts (14).

Superimposed on this distribution are estimates for the strength of the aircraft landing gear versus the design of the energy-absorbing seat (15). These estimates, taken together with the current injury experience as discussed earlier, indicate that substantial personnel loss and cost reductions will occur when the seat is fielded. It is remarkable that this modification (involving incorporation of an energy-absorbing seat and some modifications to aircraft ballistic armor) will result in little or no aircraft weight penalty. This is certainly a tribute to the aircraft manufacturer's and Army materiel developer's innovative design approach but also to the advanced state of the art of crashworthiness technology.

CONCLUSIONS

The current austere funding environment is not anticipated to improve in the foreseeable future. If aircraft crash survivability improvements are to compete with other funding requirements, then all personnel involved in the investigation, analysis or research of crash injuries must strive to achieve an enhanced data base upon which necessary management and engineering decisions can be logically based. An improved crash injury identification and reporting system developed by the US Army as described in this report is felt to be a key element of this requirement. This system appears to provide the following benefits:

- a. Identification of crash hazards in terms readily understandable by the development community.
- b. Prioritization of hazard corrective measures.
- c. Optimization of hazard corrective actions.
- d. Justification of hazard corrective measures.
- e. Adaptation of codes to future data requirements.
- f. Identification of additional research problems in the areas of crash injury and crashworthiness.

The overall goal of any crash injury analysis is to obtain improved crashworthiness designs for current and future aircraft. Based upon the benefits described above, the overall impact of this modified system of crash injury identification and reporting will be to provide the responsible project managers with the data required to adopt recommended crashworthiness improvements in new and existing aircraft and life support equipment designs.

REFERENCES

1. Berner, W. H., and Sand, L. D. Deaths in Survivable Aircraft Accidents, Aerospace Medicine, Vol. 42, No. 10, October 1971.
2. Beyneh, A. A. Helicopter Versus Fixed Wing Crash Injuries, Aerospace Medicine, Vol. 34, No. 1, January 1963.
3. Haley, J. L., Jr. Analysis of US Army Helicopter Accidents to Define Impact Injury Problems in Linear Acceleration (Impact Type). AGARD Conference Proceedings No. 88, AGARD-CP-88, pp 2-1--2-13, June 1971.
4. Haley, J. L., Jr., [and others]. Head Impact Hazards in Helicopter Operations and Their Mitigation Through Improved Helmet Design. In: Thomas, C. C., Impact Injury of the Head and Spine, Springfield, Illinois. (To be published in 1982.)
5. Mattox, K. L. Injury Experience in Army Helicopter Accidents, US Army Board for Aviation Accident Research, Ft Rucker, Alabama, AF 50-1.

6. Sand, L. D. Comparative Injury Patterns in US Army Helicopters. In: Knapp, S. C., Colonel, MC, Operational Helicopter Aviation Medicine: Ft. Rucker, Alabama. London: Technical Editing and Reproduction Ltd., pp 54-1--54-7, AGARD-CP-255, May 1978.
7. Singley, G. T. Army Aircraft Occupant Crash-Impact Protection. Army R, D & A. pp 10-12, July-August 1981.
8. Department of the Army, Aircraft Accident Prevention, Investigation, and Reporting, 1975, AR 95-1.
9. US Army Safety Center, Unpublished Data, 1982.
10. Department of the Army, Accident Reporting and Records, 1980, AR 385-40.
11. US Army Safety Center, Engineering Analysis of Crash Injury in OH-58A Aircraft, 1980, TR 79-1.
12. US Army Agency for Aviation Safety, Engineering Analysis of Crash Injury in Ch-47 Aircraft, 1980, TR 78-4.
13. US Army Agency for Aviation Safety, Engineering Analysis of Crash Injury in Army AH-1 Aircraft, 1978, TR 78-3.
14. US Army Applied Technology Laboratory, Aircraft Crash Survival Design Guide, Volume II - Aircraft Crash Environment and Human Tolerance, 1980, USARTL-TR-79-22B.
15. Personal communication between Mr. Roy Fox, Bell Helicopter Textron, and Dr. J. E. Hicks, US Army Safety Center, 5 Jan 82.

DEFINITIONS AND TERMINOLOGY

Aircraft Mishap - An unplanned event that results in aircraft damage, personnel injuries, or makes further continued flight impossible or inadvisable. Damage as a direct result of hostile fire is not a mishap 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 Costs - 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."

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 Accident - An accident in which both survivable and nonsurvivable occupant positions exist.

Velocity Change - The change in velocity of the aircraft CG during the major impact.