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**Spinal Injury in a U.S. Army  
Light Observation Helicopter  
(Reprint)**

**By**

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All accident reports involving U.S. Army OH-58 series helicopters were analyzed to determine vertical and horizontal velocity change at impact and the relationship of this kinematic data to the production of spinal injury. This analysis determined that spinal injury is related primarily to vertical velocity change at impact and is relatively independent of horizontal velocity change. The dramatic increase in the rate of spinal injury occurring just above the design sink speed of the aircraft landing gear (3.7 m/s) suggests that the fuselage and seat provide little additional impact attenuation capability above that of the gear alone. It is concluded that if this aircraft were modified to provide protection to the occupants for impacts up to 9.1 m/s (30 ft/s), approximately 80% of all spinal injury incurred in survivable accidents could be substantially mitigated. The incorporation of energy absorbing seats is recommended.

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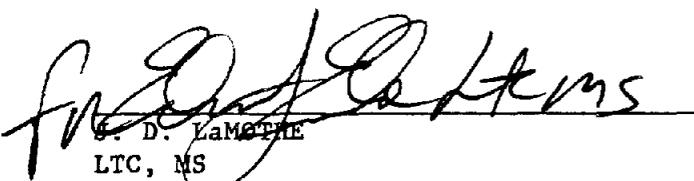
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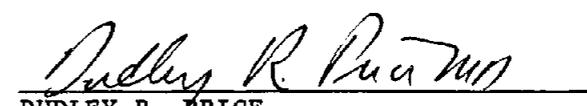
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# Spinal Injury in a U.S. Army Light Observation Helicopter

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**All accident reports involving U.S. Army OH-58 series helicopters were analyzed to determine vertical and horizontal velocity change at impact and the relationship of this kinematic data to the production of spinal injury. This analysis determined that spinal injury is related primarily to vertical velocity change at impact and is relatively independent of horizontal velocity change. The dramatic increase in the rate of spinal injury occurring just above the design sink speed of the aircraft landing gear (3.7 m/s) suggests that the fuselage and seat provide little additional impact attenuation capability above that of the gear alone. It is concluded that if this aircraft were modified to provide protection to the occupants for impacts up to 9.1 m/s (30 ft/s), approximately 80% of all spinal injury incurred in survivable accidents could be substantially mitigated. The incorporation of energy absorbing seats is recommended.**

SPINAL INJURY sustained in U.S. Army helicopter mishaps has been a major problem since the Army began using helicopters in the 1940s. The chronicity of complaints and disability from even relatively minor forms of spinal injury (i.e., so-called sprains and strains) makes them a major concern in aviation mishaps. A recent survey of injury patterns in U.S. Army helicopter mishaps (8) showed that spinal injury accounted for 10.1% of all injuries and that spinal injury comprised 15% of all major and fatal injuries. These rates have remained relatively constant over the past 25 years (2,6), indicating that relatively little has been done to reduce spinal injury from helicopter accidents in the current operational fleet.

In order to prevent any injury, it is imperative to know how it occurs. Currently, much of what is known about spinal injury mechanisms comes from studies of aircraft ejection injuries resulting from essentially pure vertical loading. There remains a need to better understand the relationship of spinal

injury to combined loading as experienced in most Army aircraft accidents involving ground impact. Furthermore, for any given aircraft design, it is important to understand the relationship of spinal injury to the design of the seat, restraint system, and the energy attenuating characteristics of the aircraft structure. Once such data have been obtained, practical means for preventing injury can be proposed. Unfortunately, in today's austere fiscal climate, the proposed solutions must be shown to be cost effective in order to be implemented for operational aircraft. This type cost analysis requires a cost estimate of the proposed "fix," which is relatively easy to obtain, and a somewhat more difficult estimate of the dollar cost of the injury one is attempting to prevent.

This paper analyzes the ground impact accident experience of a U.S. Army light observation helicopter over the past decade and relates kinematic data to the production of spinal injury. Basic injury cost data also are presented.

## MATERIALS AND METHODS

Accident reports of all OH-58 series accidents occurring between January 1971 to August 1981 were reviewed. All cases not involving a ground impact were excluded from consideration since the majority of these cases involved minor tree strikes at usually indeterminate speeds and sink rates and rarely produced sufficient decelerative forces to cause injury to the occupants. Ground impact was differentiated from a "hard landing" in that it involved either greater than incidental damage to the aircraft or injury to any of the occupants of the aircraft.

Estimates of both horizontal and vertical velocity of the aircraft's center of gravity at ground impact were made based on witnesses' statements, structural damage to the aircraft as observed in photographs, ground scarring, evidence of instrument readings at the time of impact, and comparison of damage to damage sustained in similar fully-instrumented crash tests. The injuries sustained by the occupants of the helicopter were excluded from consideration to eliminate bias

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stemming from previous conceptions of the impact forces required to produce a particular type of injury in this aircraft. The actual estimates of velocity changes were agreed upon by an aerospace engineer and a flight surgeon, both of whom were experienced in helicopter accident reconstruction. In some cases these values differed from those reported in the official accident report.

Injuries sustained and seating position were recorded for each individual involved in the 231 accidents considered. Seating position was listed as either front or back since, in the OH-58, the seats and the degree of structural protection are considerably different for these two locations. Position as to left or right side was not considered. Only spinal injuries were evaluated, and these were grouped into four categories: (a) no spinal injury, (b) sprain/strain, (c) fracture/dislocation, and (d) multiple extreme injury. While these categories are very general, they represent the best detail that could be gleaned consistently from the medical portion of the accident reports. Level of injury and greater detail as to injury type were not always available. All the categories are self-explanatory except multiple extreme injury. This type included individuals who sustained fatal injuries to more than one major body area or system. These injuries were included in this study since individuals with multiple extreme injury almost always have some degree of spinal trauma.

For each accident, the Accident Investigation Board made a determination as to the survivability of that accident. A survivable accident is defined by Army regulation as one in which the forces transmitted to the occupants do not exceed the limits of human tolerance to abrupt acceleration and in which the occupied space remains sufficiently intact so as not to "impinge upon or crush upon vital areas of the person seated in a normal position" (3). A nonsurvivable accident is one in which either of the two conditions is not met for every occupant of the aircraft. A partially survivable accident is one in which both survivable and nonsurvivable conditions exist for different positions in the same aircraft.

Injury cost for Army personnel involved in aviation mishaps is established by Army regulation (4). The estimated cost of a particular type of injury must be based on an estimate of the average days hospitalized or otherwise restricted from duty for the average person sustaining that type of in-

jury. In order to be consistent with previously published injury analyses (1,9), the U.S. Army Safety Center method of estimating costs was utilized for the three categories of injury considered. These costs have been adjusted to 1982 dollars (4). A summary of those costs is shown in Table I (1,4,9).

## RESULTS

There was a total of 258 accidents involving OH-58A or OH-58C aircraft between January 1971 to August 1981. The 231 that involved ground impacts were included in the study. There were 544 occupants involved in these accidents with 436 occupying front seats and 108 occupying rear seats. Table II shows the distribution of accidents and occupants by category of survivability, and Table III shows the distribution of occupants by injury category. It can be seen that 22.5% of the individuals involved in these accidents sustained spinal injury.

Fig. 1 is a scatter plot of all accidents according to vertical and horizontal velocity changes of each aircraft's center of gravity during its ground impact. The horizontal line in the outer rectangle is the 95th percentile vertical velocity change for all accidents. The vertical line represents the 95th percentile horizontal velocity change for all accidents. The two lines are truncated at their intersection for clarity. It should be noted that the area within the rectangle does not necessarily contain 95% of all accidents. The inner rectangle was constructed in an analogous way, but the 95th percentile lines were determined considering only survivable and partially survivable accidents.

One of the primary aims of the study was to define the relationship of spinal injury to both vertical and horizontal velocity changes at impact. Nonparametric correlation coefficients (Kendall's Tau) were calculated for both horizontal and vertical velocity changes versus injury category. Nonparametric techniques were used since injury category is not a continuous variable. These coefficients were calculated considering all accidents, and also considering only survivable and partially survivable accidents. The correlations are shown in Table IV. The general pattern shows moderate correlation between vertical velocity change and injury category and either no correlation or very weak correlation between horizontal velocity change and injury category. There was a difference in correlation depending on whether nonsurvivable accidents were considered. While only 12% of the accidents were classified as nonsurvivable, the inclusion of the injuries incurred in these accidents increases the magnitude of the correlations between both vertical and horizontal velocity changes and injury level. The addition of nonsurvivable accidents is sufficient to raise the correlation of horizontal velocity change with injury level to statistical significance. None-

TABLE I. ESTIMATE OF AVERAGE COST OF SPINAL INJURY.

Injury Type	Cost/Person
Sprain/Strain	\$ 5,470
Fracture/Dislocation	\$ 70,961
Multiple Extreme (Fatal)	\$330,000

TABLE II. ACCIDENTS AND OCCUPANTS BY SURVIVABILITY AND INJURY.

Survivability	Accidents	Occupants			Injury			
		Front	Rear	Total	None	Sprain/ Strain	Fracture/ Dislocation	Multiple Extreme
Survivable	189	383	98	481	401	25	31	4
Partially Survivable	12			25	15	0	3	7
Non Survivable	30	53	10	63	6	0	15	37
Total	231	436	108	544	422	25	49	48

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TABLE III. PERCENTAGE OF OCCUPANTS IN EACH INJURY CATEGORY.

Injury	Occupants	Percent of Total
None	422	77.5
Sprain/Strain	25	4.5
Fracture/Dislocation	49	9
Multiple Extreme	48	9

theless, the correlation with vertical velocity change remains two-and-a-half times larger. Fig. 2 and 3 are histograms showing the mean ( $\pm 1$  S.D.) of the vertical velocity for each injury category for survivable and partially survivable accidents, and for all accidents respectively. These graphs show the positive relationship between vertical velocity and injury.

To more precisely define the functional relationship between vertical and horizontal velocity change and the production of spinal injury, a series of curves were drawn depicting the relative frequency of injury for those exposed to impact. These curves were constructed by dividing the range of velocity change into 3.05 m/s (10 ft/s) intervals for vertical and horizontal velocity changes. For each 3.05 m/s interval there were a certain number of occupants exposed. The number of occupants sustaining a certain type of injury di-

vided by the total number exposed to that level of velocity change yields the relative percentage of individuals receiving that injury over that increment of velocity change.

Since there were four categories of spinal injury, a family of four curves was drawn for vertical velocity change and another set for horizontal velocity change. Survivable/partially survivable accidents and all accidents were considered separately. These graphs are shown in Fig. 4, 5, 6 and 7. It is fairly obvious that spinal injury has little or no systematic relationship to horizontal velocity change in these accidents (Fig. 4 and 5). However, there is a relationship between spinal injury and vertical velocity change (Fig. 6 and 7). It should be noted that these curves represent the incidence of each type of injury occurring alone. Consequently, it appears, for example, that the incidence of fracture begins to decline after 6.1 m/s (20 ft/s) (Fig. 6 and 7), when in reality this injury simply rarely occurs as an isolated event after 6.1 m/s vertical velocity change. It is overshadowed by more extreme injuries, and this is reflected in the marked increase in multiple extreme injuries occurring above this level. An analogous situation exists for sprains/strains although it is not as dramatic. It is interesting that the curves depicting sprain/strain and fracture/dislocation show the same initial slope up to 6.1 m/s vertical velocity change (Fig. 6 and 7). This suggests that there is not a clear distinction between the

Fig. 1. Scatter plot of vertical velocity change versus horizontal velocity change at impact for 231 ground impact accidents.

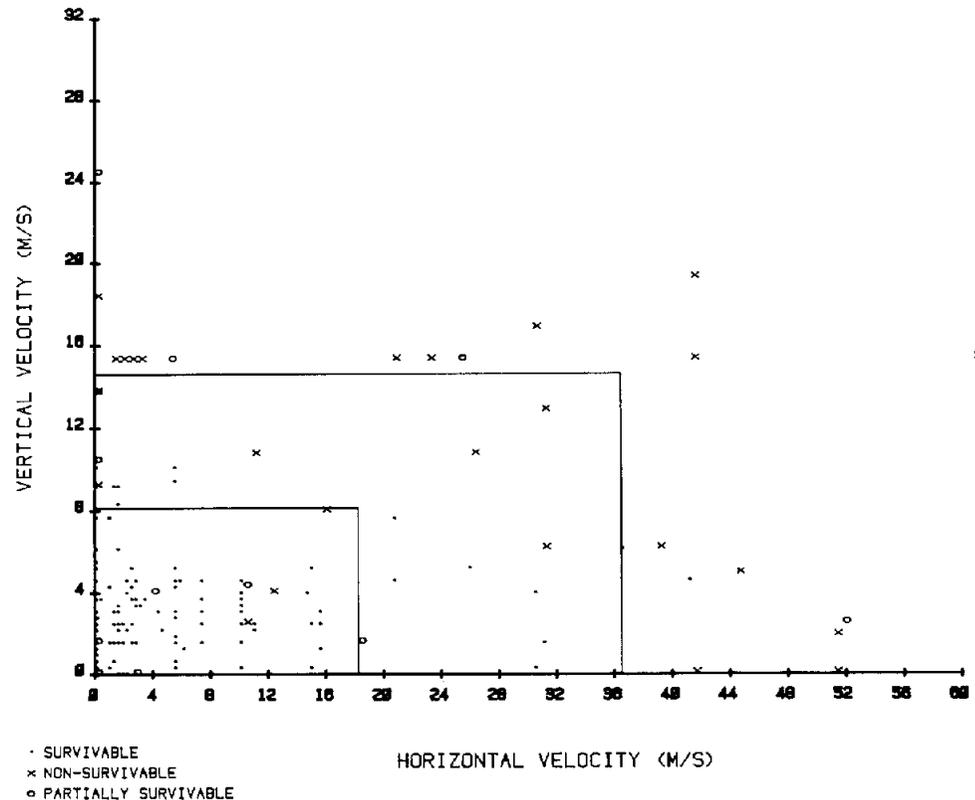


TABLE IV. KENDALL'S TAU COEFFICIENTS FOR INJURY AND IMPACT VELOCITY.

Survivability	Correlation	Tau	Significance
Survivable, Partially Survivable	Vertical Velocity $\times$ Injury	0.401	0.001
Survivable, Partially Survivable	Horizontal Velocity $\times$ Injury	-0.013	n.s.
ALL	Vertical Velocity $\times$ Injury	0.450	0.001
ALL	Horizontal Velocity $\times$ Injury	0.173	0.001

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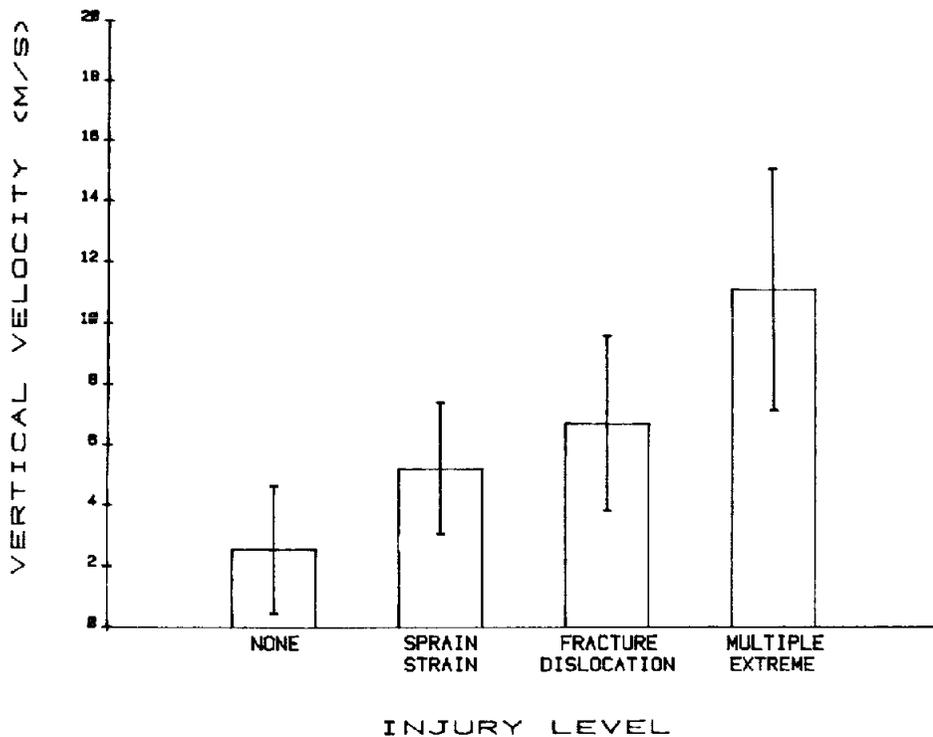


Fig. 2. Mean vertical velocity change at impact for each injury category for survivable and partially survivable accidents. Error bars represent 1 S.D.

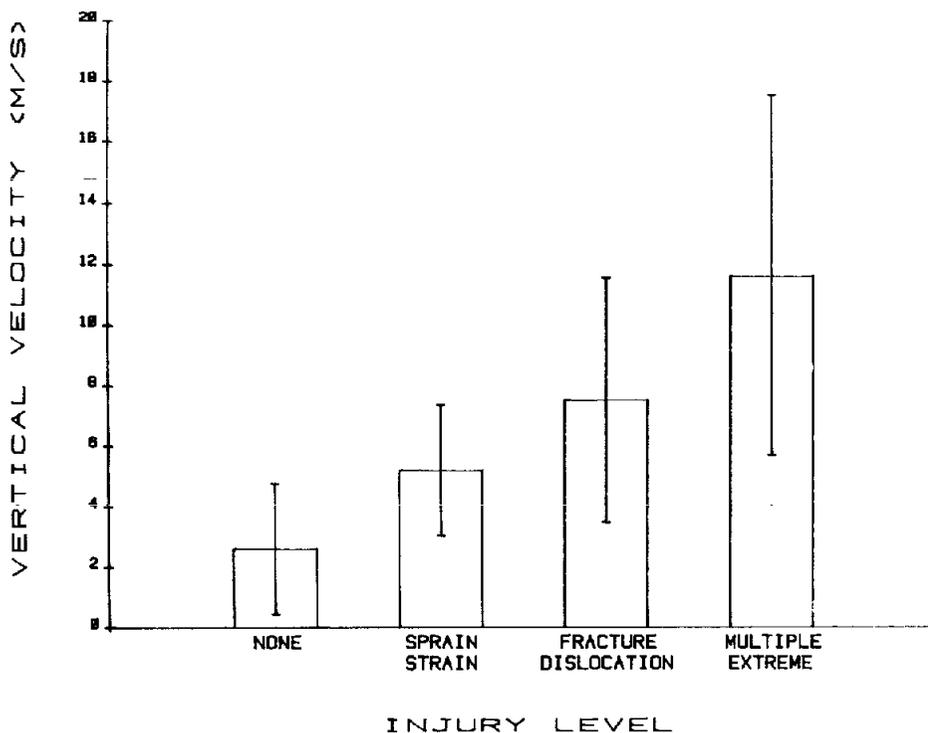


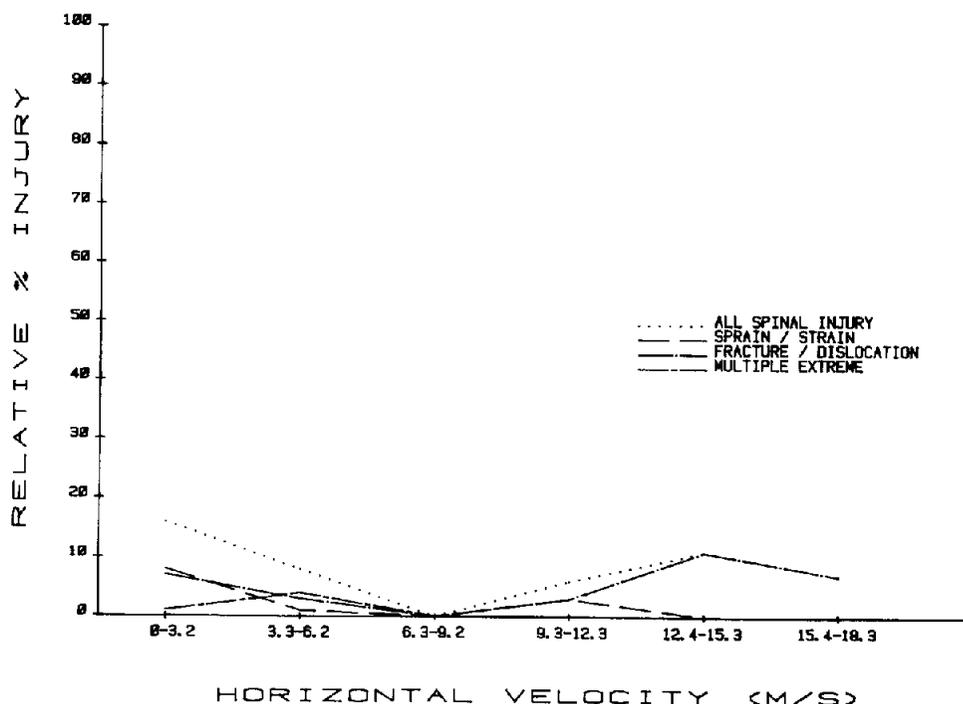
Fig. 3. Mean vertical velocity change at impact for each injury category for all accidents. Error bars represent 1 S.D.

input energy required to cause these two types of injury and that other factors must dictate which of the two injuries will occur at these input levels.

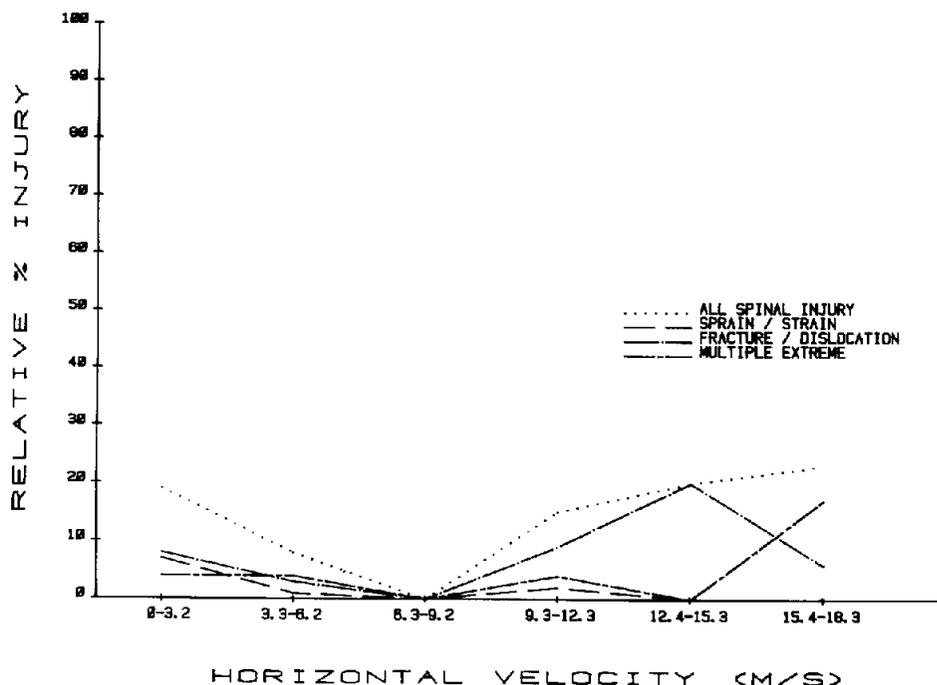
Fig. 8 and 9 were constructed to emphasize the dependence of spinal injury production on vertical velocity change at impact and to show the lack of systematic correlation between vertical and horizontal velocity change. Fig. 8 represents survivable and partially survivable crashes while Fig. 9 represents all crashes. Within each injury category, vertical

velocity change was regressed on horizontal velocity change. The regression lines were plotted over the range of horizontal velocity change up to the 95th percentile horizontal velocity change, 18.3 m/s (60 ft/s). The shaded area around each line encloses  $\pm 1$  S.E. of the estimate. None of the linear regressions was statistically significant indicating that knowledge of either vertical or horizontal velocity change does not allow one to predict the other velocity component within an injury category. There is a slight trend toward negative correlation

**Fig. 4. Relative percent spinal injury as a function of horizontal velocity change at impact for survivable and partially survivable accidents.**



**Fig. 5. Relative percent spinal injury as a function of horizontal velocity change at impact for all accidents.**



between vertical and horizontal velocity change which suggests a tendency for increased horizontal velocity change to require less vertical velocity change to produce a certain type of injury. Again this representation clearly shows the poor distinction between the magnitudes of vertical velocity change required to produce sprains/strains and fracture/dislocations. Above approximately 4.6 m/s (15 ft/s) vertical velocity change, the risk of either type of injury escalates dramatically.

A similar analysis was attempted based on seating position of the individuals involved in these accidents to determine if there were any differences between front and rear seating

positions in regard to threshold velocity changes required to produce spinal injury. Although there were not statistical differences in either horizontal or vertical velocity changes between front and rear seating positions for no injury, sprain/strain, and fracture/dislocation, it is noteworthy that no individuals in rear seats sustained multiple extreme injuries. This is probably because the rear portion of the cabin is considerably stronger structurally than the forward portion and remains relatively intact in most accidents compared to the front portion of the cabin. Therefore, rear seat occupants are better protected from crushing injuries and main rotor intrusion than the front seat occupants. Furthermore, as shown

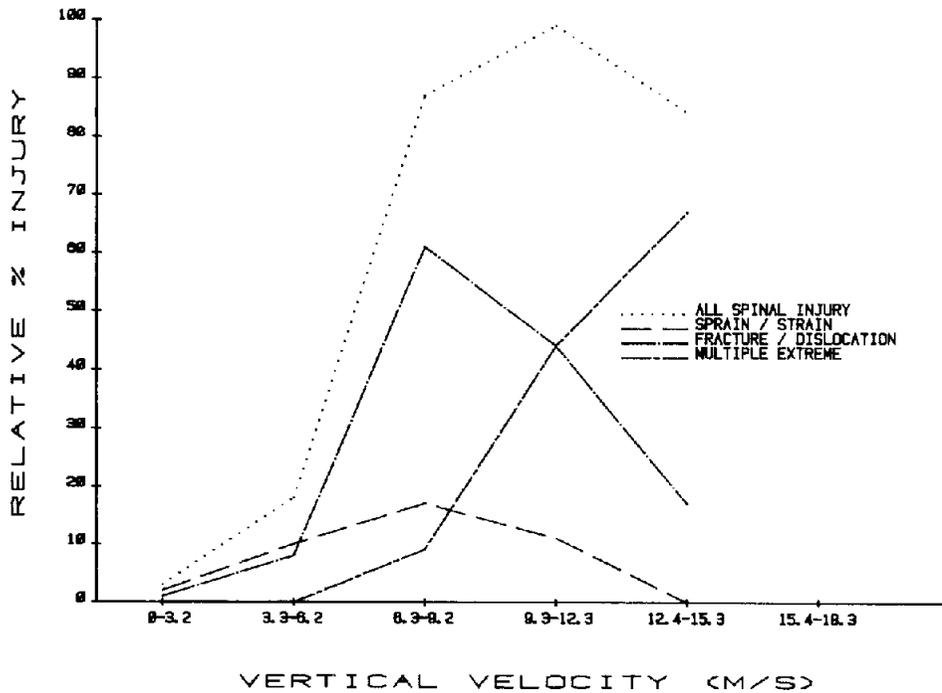


Fig. 6. Relative percent spinal injury as a function of vertical velocity change at impact for survivable and partially survivable accidents.

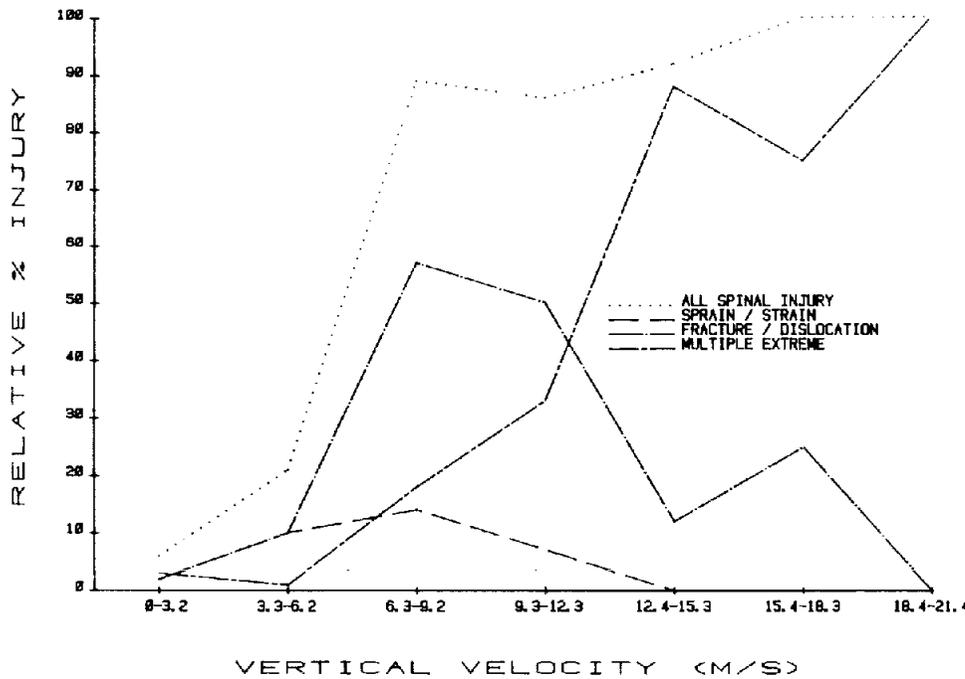


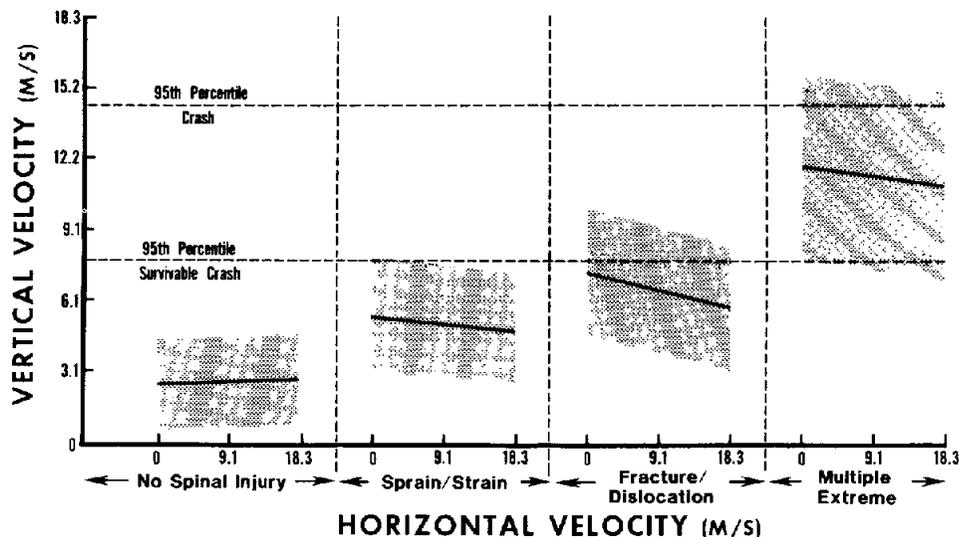
Fig. 7. Relative percent spinal injury as a function of vertical velocity change at impact for all accidents.

in Table II, only 10 individuals sitting in rear seats were exposed to nonsurvivable accidents which are most likely to produce multiple extreme injury.

Table V is a summary of the estimates obtained for direct costs to the government for each type of spinal injury incurred both over the study period and over the projected life cycle (20 years) of the OH-58. The \$36 million cost must be regarded as the maximum potential savings obtainable by any crashworthy improvements directed toward reducing spinal injury. The majority of this cost is due to multiple extreme injuries incurred in accidents categorized as nonsurvivable. Since this group is comprised of individuals with fatal injuries to multiple organs, it is unlikely that crash-

worthy improvements primarily directed toward reducing vertical loads will prevent many of these fatalities. On the other hand, if only survivable and partially survivable accidents are considered as shown in Table VI, it is reasonable to assume that a relatively large portion of these injuries could be prevented or reduced with significant crashworthiness improvements. Fig. 10 demonstrates that 80% of all spinal injuries in survivable and partially survivable accidents occur at vertical impact velocities of less than 9.1 m/s (30 ft/s). Therefore, if design changes were incorporated in the aircraft so as to provide protection to the occupants for vertical impacts up to 9.1 m/s, a potential savings of approximately \$9.2 million in injury costs could be realized over the

**Fig. 8.** Plot of vertical versus horizontal velocity change at impact for each injury category considering only survivable and partially survivable accidents.



**Fig. 9.** Plot of vertical versus horizontal velocity change at impact for each injury category considering all accidents.

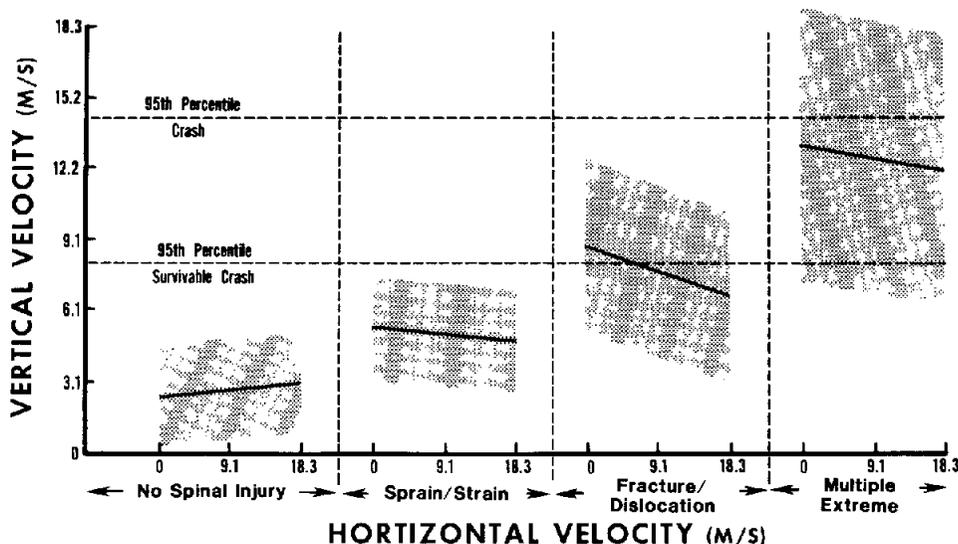


TABLE V. ESTIMATE OF SPINAL INJURY COST—ALL ACCIDENTS.

Injury Type	Period of Study (1971-1981)		Projected 20 Yr. Cost (FY 82\$)
	No. of Cases	Cost (FY 82\$)	
Sprain/Strain	25	\$ 137,000	\$ 256,000
Fracture/Dislocation	49	\$ 3,477,000	\$ 6,502,000
Multiple Extreme	48	\$15,840,000	\$29,621,000
<b>Total</b>	<b>122</b>	<b>\$19,454,000</b>	<b>\$36,379,000</b>

TABLE VI. ESTIMATE OF SPINAL INJURY COST—SURVIVABLE AND PARTIALLY SURVIVABLE ACCIDENTS.

Injury Type	Period of Study (1971-1981)		Projected 20 Yr. Cost (FY 82\$)
	No. of Cases	Cost (FY 82\$)	
Sprain/Strain	25	\$ 137,000	\$ 256,000
Fracture/Dislocation	34	\$2,412,674	\$ 4,508,354
Multiple Extreme	11	\$3,630,000	\$ 6,788,100
<b>Total</b>	<b>70</b>	<b>\$6,179,674</b>	<b>\$11,552,454</b>

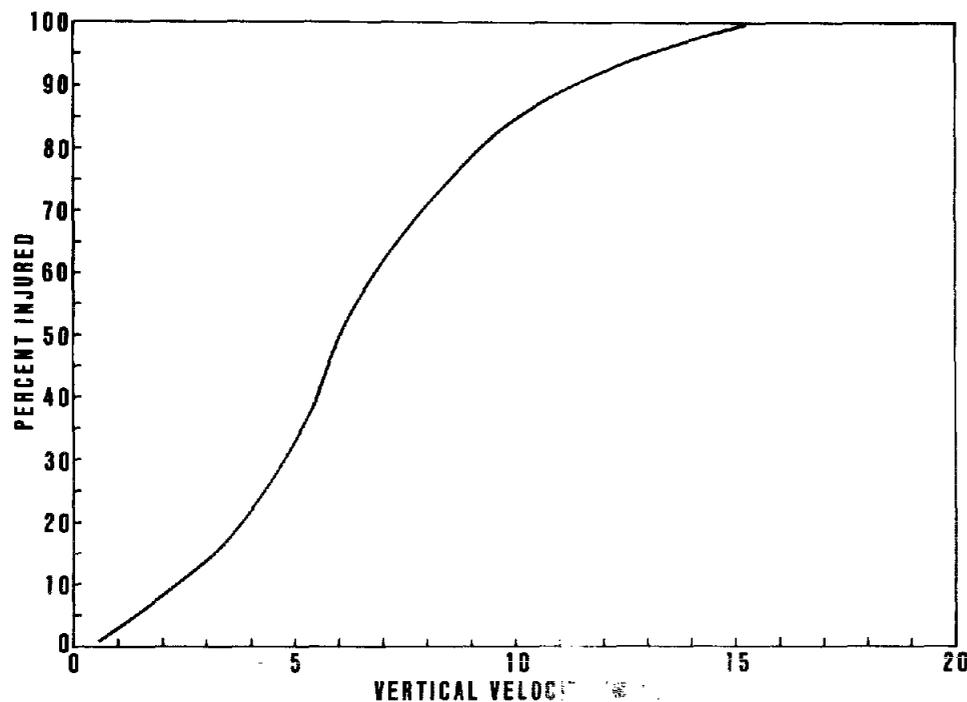


Fig. 10. Cumulative percent injury versus vertical velocity change at impact for survivable and partially survivable accidents.

life cycle of the aircraft if there is no change in fleet size. A significant injury reduction also would be realized in those survivable and partially survivable accidents occurring above 9.1 m/s vertical velocity change, as well as for some accidents now considered nonsurvivable, but a specific estimate cannot be made from the data available. Consequently, \$9.2 million can be regarded as a very conservative estimate of the potential injury cost savings of providing vertical impact attenuation capability of 9.1 m/s in this particular aircraft.

## DISCUSSION

Analysis of 231 OH-58 accidents demonstrates that spinal injury is primarily related to vertical velocity change at impact and is relatively independent of horizontal velocity change. This relationship of spinal injury to vertical velocity change is due to several factors:

- 1.) The human body in general and the spinal system in particular are better able to tolerate horizontally applied loads ( $G_x$ ) than vertical loads ( $G_z$ ).
- 2.) Vertical stopping distances in these accidents are generally much less than horizontal stopping distances. Thus, for a given velocity change, the vertical loads produced are higher than the horizontal loads.
- 3.) Upper torso restraint is available for all seating positions in the OH-58 and prevents high degrees of spinal hyperflexion in most accidents.
- 4.) The front seats of the OH-58 suspend the buttocks of the occupant only one to two inches above a rigid armor plate. Thus, in impacts of sufficient force to allow the buttocks to contact the armor plate, peak vertical loads on the occupant will be greatly amplified through the mechanism of dynamic overshoot. Consequently, any efforts made toward reducing spinal injury in this aircraft should be directed primarily toward reducing vertical loads on the occupants during impact.

It has been shown that the incidence of spinal injury increases dramatically above a vertical velocity change increment of 3.4–6.1 m/s (Fig. 6 and 7). The study also has shown

that if crashworthiness improvements were made to provide protection to the occupants for impacts up to 9.1 m/s vertical velocity change, 80% of all spinal injury incurred in survivable and partially survivable accidents could be substantially mitigated. The current design sink speed of the landing gear on the OH-58 is 3.7 m/s (12 ft/s) (1). This is the maximum sink rate for which the landing gear is designed to prevent fuselage-ground contact. The fact that there is a significant increase in spinal injuries for impacts just above 3.7 m/s suggests that the fuselage and seat provide little or no vertical load attenuation above that of the gear alone. The incorporation of energy attenuating seats into the current airframe for at least the pilot and copilot positions either alone or in conjunction with modification of the landing gear would probably be the most economical means of increasing the vertical impact attenuation capability of the aircraft to 9.1 m/s. Such a retrofit program is technically feasible and would require relatively minor alterations to the aircraft structure.

In evaluating the cost effectiveness of making the above recommended crashworthiness improvements, it should be stressed that almost a quarter (22.5%) of individuals exposed to a ground impact in the OH-58 suffer some degree of disability from spinal trauma. Although comparison data is not currently available for other aircraft, this injury rate appears alarmingly high, and would represent a significant source of pilot attrition in a combat situation.

Since impacts involving equivalent vertical velocity changes produce different types of injuries, other factors are also important in determining type and degree of injury. Certainly, human variability accounts for much of this observed difference as do the relatively imprecise methods for estimating velocity changes. However, external forces that produce rotational moments in the spine in conjunction with flexion and compression are probably of equal importance (5,7). In this analysis pure vertical and horizontal velocity changes at impact were considered since these were the only kinematic data which could consistently be determined with a reasonable degree of accuracy. There is a proposal to equip U.S.

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Army aircraft with flight data recorders, and a part of this package would measure accelerations and loads at impact. Perhaps, in the future, such a system will allow the analysis of spinal injury with respect to all kinematic parameters, and thus help to better explain the relationship between force input parameters and resulting spinal injury.

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