Aircraft Impact and Injury Patterns in US Army Accidents from 2003 to 2005

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Abstract

Objective: Aircraft seating has become increasingly sophisticated and expensive as improved dynamic performance standards are used. Establishing feedback data from actual accidents is important for comparing safety relative to other factors such as cost and weight. Seat and restraint performance is measured by design standards using simple triangle-shaped impact vectors. Real world crash impacts and the injuries sustained are rarely evaluated for small aircraft in particular. The lack of data provides scarce data to judge the efficacy of crashworthiness design efforts. A unique source of impact and injury data is the US Army Combat Readiness Center database at Ft. Rucker. Research was conducted under a Co-operative Research and Development Agreement (CRDA) between AmSafe Aviation and the US Army Aeromedical Research Laboratory with the objective to evaluate both the vehicle impact and the injury patterns. *Methods:* Data inquiries containing pre-impact flight information, estimates of aircraft impact forces, and occupant injury patterns were evaluated for accidents with a resultant impact vector greater than 20 g. *Results:* Crash impact characteristics and injury distributions are presented for 156 accidents and 606 occupants. Methods for evaluating aviation accidents with respect to the impact vector are discussed. *Conclusions:* Combined evaluations of both the impact and injury are needed for understanding the efficacy of modern crashworthy design. The methods for collecting post crash impact data need to be improved for access and standardized for objectivity. Regarding helicopter crashes in general, all impact orientations are significant.

Introduction

Aircraft safety progresses on two fronts, avoiding accidents and providing protection for those crashes that are survivable. Averting the crash is of course preferred, but when they do occur, the installed equipment should provide the best survivability envelope possible. Safety and perception of risk affect the design, and must be balanced with factors such as cost, weight, occupant comfort and maneuverability. Data from actual crashes is needed to properly assess relative benefit and make informed design choices.

Over the last few decades, studies found both military and civil aircraft interiors inadequate. A transformation of aircraft interiors has occurred, as documented in various design guides including: the US Army Crash Survival Design Guides (Coltman 1989, Desjardins 1989); USDOD Crew Systems Crash Protection Handbook (USDOD 1998), and the AGATE Small Airplane Crashworthiness Design Guide (Hurley 2002). Survivability studies beginning in the 1970's supported a change from static to dynamic load conditions in the 1980's. These have forced changes in seats and restraints that began in the late 1980's and continue today.

Has the investment in safety technology produced the benefits desired? How should these efforts be prioritized in the future? The answers require comparison to established benchmarks. The impact levels required by regulations provide benchmarks and a measure of the survivability envelope. Dynamic design loads for aircraft seats and restraints consist of idealized acceleration pulses representing the impact acceleration transferred through the floor to the seats. For example, the combined forward and downward impact vector for civil and military helicopters range from impact severities of 30 g peak acceleration with 30 ft/s velocity change to 50 g and 42 ft/s velocity change. (ECFR, USDOD 1998)

The regulations also represent design limits for injury mitigation. Engineers design seats and restraints to function within this envelope. However the efficacy of these designs requires developing an understanding of the injury trends to vehicle impact levels. Survival factors data for small aircraft accidents would provide a means to develop these trends, but this information is not collected for civil aircraft accidents as it is in US Army accidents. The objective of this research was to conduct an initial evaluation of aircraft accident data combining both vehicle impact and injury data and to explore methods of measuring the benefit of modern crashworthy equipment.

Survivability studies providing a large sample comparing injury patterns to crash characteristics are virtually non-existent. FAA and NTSB survivability studies conducted prior to wide usage of dynamically certified seats incorporate impact levels on a case by case basis (Kirkham 1982; NTSB-AAS-81-2; NTSB/SR-83/01; NTSB/SR-85/01; NTSB/SR-85/02). The FAA benefit analysis for transport aircraft 16 g passenger seats notes the relationship between impact severity and injury potential, however only one of the 25 accidents evaluated references estimated impact accelerations (Cherry 2000). Various studies of individual incidents exist, such as the studies from the Kegworth disaster (UKCAA 1989), and specific military studies (Hicks 1982, Shannahan 1984). Apart from the US Army Combat Readiness Center database, there is no repository of accident data with sufficient detail for comparing injury patterns and survivability.   The infrequent and individual nature of transport aircraft crashes does not lend itself to this sort of data collection. However civil rotorcraft and general aviation accidents can be sources of this data.

Methods

This research explores methods for collection and analysis of accident data as feedback for the crashworthy design process. A unique source of this data for aircraft accidents is the US Army Combat Readiness Center database at Ft. Rucker. Research was conducted under a Co-operative Research and Development Agreement (CRDA) between AmSafe Aviation and the US Army Aeromedical Research Laboratory with the objective to evaluate both the vehicle impact and the injury patterns. The US Army data was collected and initial evaluations performed. This provides insight for the type of data that should be collected and evaluated for civil aircraft accidents.

The evaluations are focused on either the aircraft impact or the occupant injuries, which are treated separately in the methods and results. The inclusion criterion includes all non-combat US Army aviation accidents from the US Army database. Excluded are: accidents outside the date range 1983-2006; cases with no injury data reported; accidents with acceleration components (longitudinal and vertical and lateral) below 20 g.

AIRCRAFT ACCIDENTS

The impact assessment evaluates the primary crash impact according to the six component directions to determine if any appear prominent. The impact vectors consist of peak acceleration estimates, reported by the accident investigator in units of g, for each of the six directions: Left / Right; Fore / Aft; Up / Down. The evaluation attempts to characterize the impact vectors in three ways.

- Frequency of Occurrence (number of times an impact value was recorded)
- Portion of Total Impact (ratio of the component to resultant)
- Impact Severity (frequency of impacts occurring in various severity ranges)

Frequency of Occurrence

The impact acceleration field contains a value and direction, a zero, or is empty. The blank or zero fields are assumed to be a neutral orientation for that axis pair. In order to evaluate the frequency of the various impacts occurring, the number of citations are counted and expressed as a percentage for that axis pair. For example, the Forward / Aft impact direction contains impact values other than 0 for 140 of the 156 accidents. The 140 citations consist of 86 in the Forward direction and 52 Aft. Thus the forward direction occurs in 51%, the Aft in 33%, and neutral 16%.

Portion of Total Impact

Breaking the impact down into components simplifies the evaluations, but the interaction as a portion of the total must be considered. The ratio of each component to the resultant impact value is observed. The impact resultant and component ratios are calculated as shown below.

$$\text{Resultant Impact for each Accident} = (\text{Longitudinal}^2 + \text{Lateral}^2 + \text{Vertical}^2)^{0.5}$$

$$\text{Impact Ratio for each Direction of Each Accident} = \text{Component Value} / \text{Resultant}$$

This generates a ratio value for each of the 156 accidents distributed among the 6 possible directions. In order to compare the impact directions, a summation of each is created according to the bottom, middle, or top third percentiles. For example, the Downward Impact direction is cited in 54 of the 156 accidents. Of these, 16 had a ratio below 0.33, 4 in the range 0.33 to 0.66, and 33 in the range 0.66 to 1.0. Expressed in percentages, the bottom, middle, and top thirds are 30%, 9%, and 61% respectively. This suggests that most downward impacts are a large portion of the total.

Impact Severity

The frequency of impacts for a particular direction in a range of acceleration values is assessed. Four acceleration ranges have been used: 0 to 25 g; 26 to 50 g; 51 to 75 g; and Above 75 g. These ranges were selected to provide detail in the survivable range. An impact component above 75 g can generally be assumed non-survivable. The number of impact citations in each range for each impact direction are counted and then expressed as a percentage of the total non-zero values for that direction.

OCCUPANT CASES

A case is defined as an occupant with injuries listed for each of the 156 accidents evaluated in the aircraft impacts. Each occupant case consists of a list describing the injured body part(s). The evaluation groups the listings in terms of the body region and body part type. The limitations of the occupant injury evaluation are:

- Not all occupants are accounted for in each accident.
- No consistent protocol was used for the injury listings in the database, thus some cases only severe injuries may have been listed while others may have a more compete listing.

- Some injury listings are specific (T1 vertebra), others are general (thoracic vertebra). Indeterminate listings such as “general body”, or “vertebra” (unknown if cervical, thoracic, or lumbar) were eliminated.
- Occupant location in the aircraft, seating configuration, or restraint type were not taken into account.

Study Parameters and Background Information

The process of collecting and organizing the data for evaluation provided information that is helpful for understanding the population of the aircraft accidents and occupants. These parameters may also provide a useful basis for further evaluations which were beyond the scope of this research. For example, the evaluations could be repeated for specific aircraft types.

AIRCRAFT ACCIDENTS

There were 156 total aircraft accidents with the following aircraft types Involved:
OH58, 21% (n=32); UH60, 20% (31); UH1, 16% (n=25); AH64, 15% (n=23); CH47/MH47, 6% (9); AH1, 4 (n=6) and all others, including fixed wing aircraft 19% (n=30). Figure 1 illustrates the six most frequent aircraft types. Each accident is classified according the severity determined by the investigator. The 156 aircraft accidents are listed as: Non-survivable (65.6%); Partially survivable (19.8%); Survivable (12.7%); and 1.9% are Not-specified.

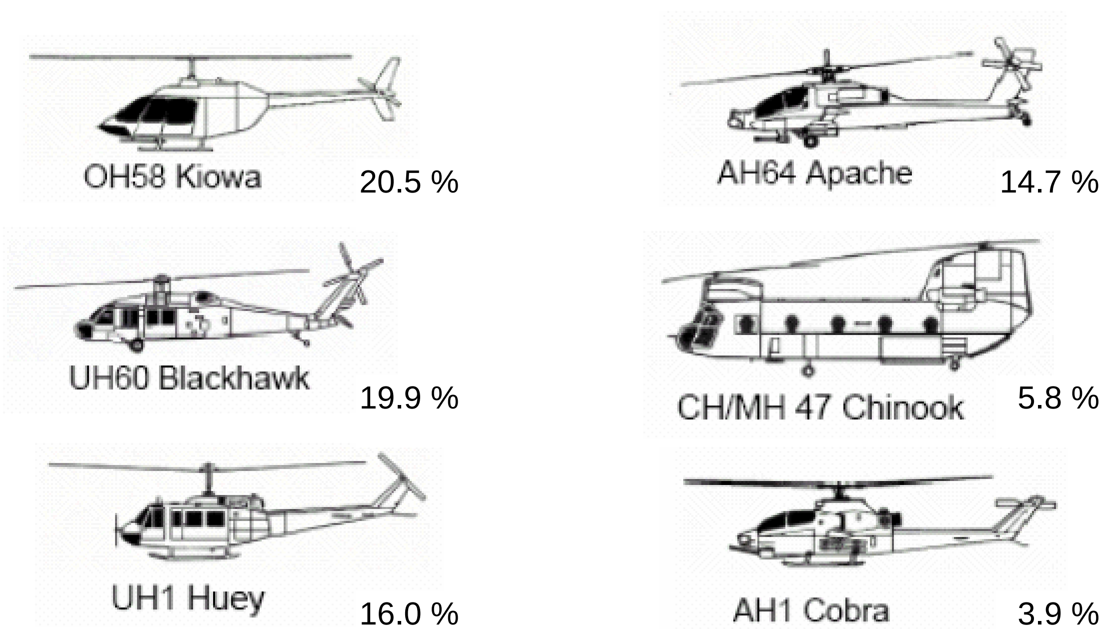

Figure 1. Most Common Aircraft Types in Accident Database

OCCUPANT CASES

There are 606 Occupants evaluated. The gender distribution is 98% male, 1.6% female, and 0.4% unknown. The age range is 19 to 61 for the 379 of 606 reported. The average age is 32, and the most frequent age is 26. Each case is classified according to the severity of injuries. Fatalities are 67.2% (407) and non-fatal are 32.8% (199). The non-fatal are further listed from minor to severe as: First Aid 8% (16); Lost Work 70.9% (141); Permanent Partial Disability 19.1% (38); Permanent Total Disability 3.5% (7); and 1 not reported. There are 2533 listings for the 606 occupants. Of these, a total of 297 were eliminated as too general, 254 fatal and 43 non-fatal. The number of injuries classified are 1635 fatal and 601 non-fatal.

Results

The research evaluates both aircraft impact and injuries for those accidents. The results are organized by assessing the aircraft impact and injury separately, and then comparisons of the two are presented.

AIRCRAFT ACCIDENTS

Frequency of Occurrence

The frequency of reported values indicated that no particular orientation was clearly prominent. The percentage of citations according to each axis pair is provided in Figure 2 below. The values add up to more than 100% because up to 3 axis can be recorded for each accident. The total values do not add up to 300% because the neutral percentages are not listed in the figure. The neutral percentages for each axis pair are: For/Aft 16%, Up/Down 10%, Left/Right 34%.

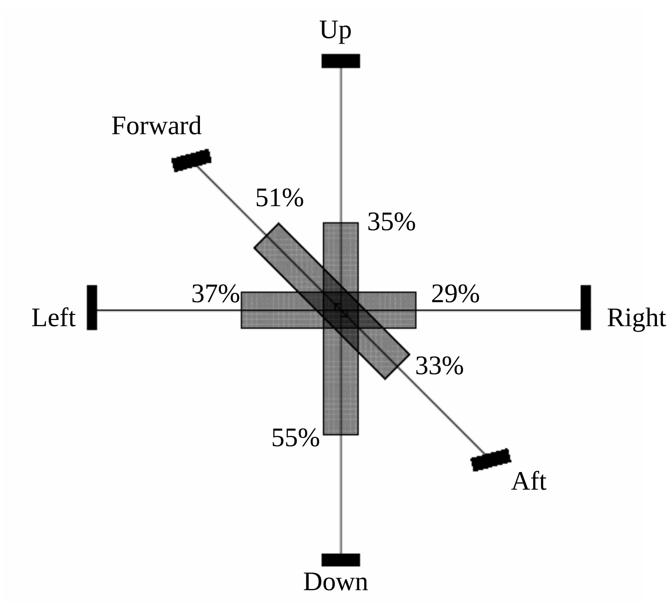

Figure 2: Frequency of Accidents per Impact Vector

Ratio of Impact Direction to Total

Table I indicates how a particular impact direction is associated with the resultant impact. The summation of the impact ratios for all accidents with a non-zero value in the specified direction is expressed as a percentage of the total. The ratio values are grouped in thirds according to the bottom, middle, and top portion of the total impact. A large percentage in the bottom third indicates that direction was often a minor portion of the total impact. A large number in the top third indicates that this direction was often the primary impact direction.

Table I: Ratio of Impact Component / Total Impact

Percentile	**Left**	**Right**	**Fore**	**Aft**	**Up**	**Down**
Bottom Third (Ratio = 0 to 0.33)	56%	71%	40%	33%	23%	30%
Middle Third (Ratio = 0.34 to 0.67)	23%	16%	26%	25%	8%	9%
Top Third (Ratio = 0.68 to 100)	21%	14%	34%	42%	69%	61%

Impact Magnitude

The impact magnitude indicates the relative severity and is presented by the giving the frequency distribution for a range of impacts as described in the methods. Table II represents how often a particular direction had an impact occur within each acceleration range. Specifically, the values are the percentage of the impacts cited for that range and direction.

Table II: Impact Magnitude Distribution

Impact Severity Acceleration (g)	**Left**	**Right**	**Fore**	**Aft**	**Up**	**Down**
0 to 25	63%	64%	50%	35%	28%	37%
26 to 50	13%	22%	18%	21%	30%	30%
51 to 75	0%	4%	3%	4%	12%	7%
76 and Above	25%	9%	30%	40%	30%	26%

OCCUPANT CASES

The injury listings are first presented by region in Table III and Figure 3. Table IV then provides the injury listings according to body part.

Table III: Injuries by Body Region

Region	**Total**	**Fatal**	**Non-fatal**	**%Fatal**	**%Non-Fatal**
Above Shoulder	805	606	199	37	33
Uppr Torso	628	551	77	34	13
Lower Torso	379	272	107	17	18
Upper Extremities	171	87	84	5	14
Lower Extremities	253	119	134	7	22
Total	2236	1635	601	100	100

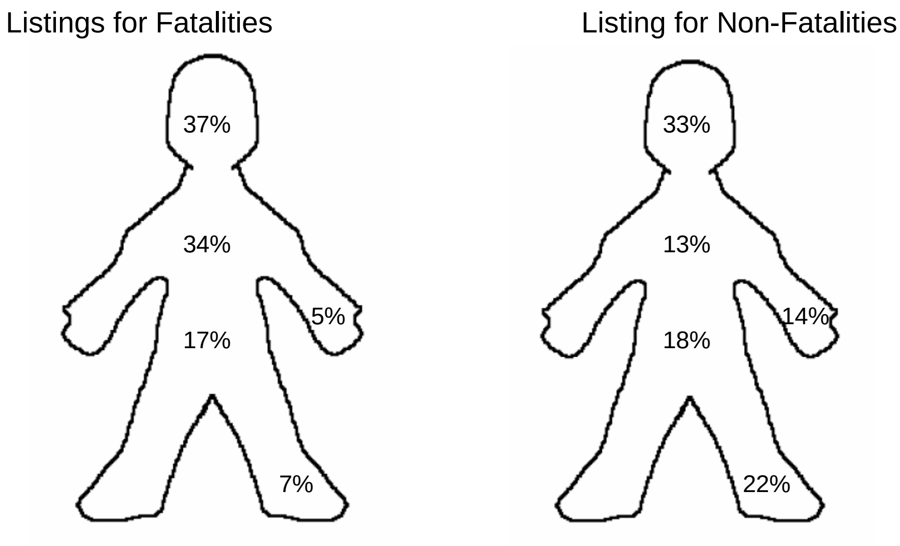

Figure 3: Injuries According to Body Region

Table IV: Injuries by Body Part

Part	**Total**	**Fatal**	**Non-fatal**	**%Fatal**	**%Non-Fatal**
Head/Skull/Brain	551	462	89	28	15
Face/Jaw	132	45	87	3	14
Neck, C1-C7	122	99	23	6	4
Upper Organs (Heart, Aorta, Lungs)	372	355	17	22	3
Upper Torso (chest, ribs, Thoracic Vert)	256	196	60	12	10
Lower Organs (abdo, bladder, diaph, kidney, liver, pancreas, spleen, stomach, intestines)	202	172	30	11	5
Lower Torso (Hip, Pelvis, L1-L4)	177	100	77	6	13
Upper Extremities	171	87	84	5	14
Lower Extremities	253	119	134	7	22
Total	2236	1635	601	100	100

Discussion

IMPACT ASSESSMENT

Rotorcraft accidents were the vast majority (98%) of data available, and the study provides data from a significant sample size. This research suggests that all impact directions are significant from a frequency perspective. In general, forward and downward impacts appear to be somewhat more common than the others, but not to the extent that the others should be discounted. These results provide a good basis for further evaluation according to individual impact orientations and individual aircraft types. The aircraft type and mission are expected to affect the distribution of impact and injury patterns.

The impact ratio assessment suggests that lateral impacts are generally a small portion of the total, that vertical impacts tend to be the predominant portion of the total, and that longitudinal are roughly evenly split across the ratio tiers. This ratio provides a perspective for understanding the component's relationship to the whole event. However the limitations in the methods of recording this data must also be considered. The recorded impact accelerations may be confounded with predispositions of the investigator. For example, lateral impacts appear to constitute a minor portion of the total, but this could be caused by a focus on the vertical and longitudinal axes by the investigators. Also, the lack of middle values in the vertical axis may suggest a predisposition to classify an impact as either very minor or very severe.

The impact magnitude evaluation provides a means to estimate the survivability envelope from the accident data. Figure 4 plots the percentage of accidents reported as a function of the resultant impact acceleration. Fatal, Non-Fatal, and all of the accidents together are represented. The fatal curve increases even while the total for all accidents decreases. Fatal case listings are most frequent at about 100 g. The non-fatal and fatal curves cross at about 60 or 70 g. About 95% of the non-fatal accidents occur below 125 g.

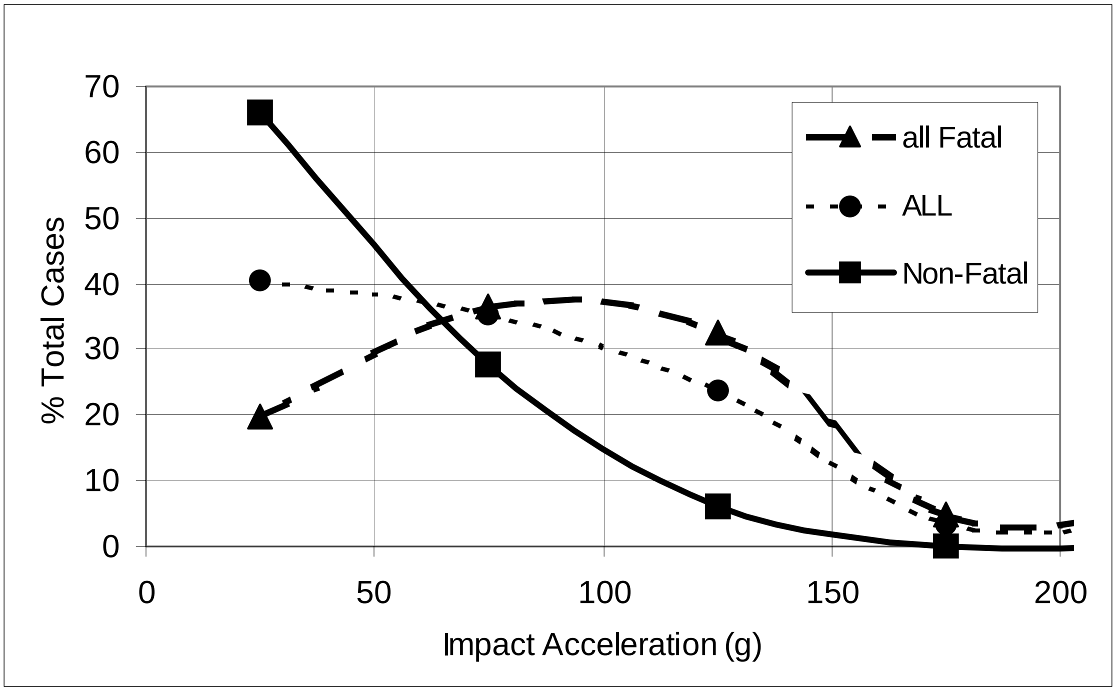

Figure 4. Accident Frequency vs Impact Resultant

OCCUPANT CASES

A similar study with both crash and injury data is published in volume II of the Aircraft Crash Survival Design Guide (ACSDG), page 24-27 (Coltman 1989). That study is based on the same database, but for an earlier time period (1980 to 1985). The focus was the type of aircraft and the terrain at impact, while this study is focused on the relationship between injuries and the severity / direction of impact. A comparison of injury by body region indicates very similar results, and is shown in table V. Note that the selection criteria are somewhat different between the two studies. The thorax abdomen and vertebra are combined because the thoracic bones and organs were not separately defined in the ACSDG study.

Table V: Injury by Body Region Results, This Study and ACSDG Vol. II

This Study			ACSDG Vol. II (All Mishaps 1980 to 1985)		
Part	Fatal	Non-Fatal	Part	Major / Fatal	Fatal
Head/Skull Brain/Face/Jaw	31%	29%	Head* (general)	27%	41%
Neck (C1 – C7)	6%	4%	Neck and Cervical Spine	4%	4%
Upper Torso/Lower Organs/Vertebrae	51%	31%	Thorax/Abdomen/Vertebrae	44%	49%
Upper Extremities	5%	14%	Upper Extremities	7%	0%
Lower Extremities	7%	22%	Lower Extremities	14%	0%
General	(not counted)		General	4%	6%

The injury distribution supports the common conclusion that head injury is very important for all accident severities. This study also lists bony and organ injuries of the chest and abdomen separately. Table IV illustrates that organ injuries in fatal accidents are on par with head injuries but rare in non-fatal accidents. Non-fatal accidents conversely have a much higher frequency of bony injuries to the upper and lower thorax. Determining how this affects survivability requires more detailed analysis, and was beyond the scope of this research.

Figure 5 provides a rudimentary evaluation to illustrate further analysis methods which can relate the injuries to crash impacts. The injury listings (all) for various body parts are graphed relative to the resultant impact. It suggests that upper torso injuries are nearly as common as head injuries for low severity crashes, and more significant than one would have concluded by looking at the injury distribution of table IV alone. It also shows that heart and aortic injury are relatively uncommon in low to moderate severity crashes. Evaluations of this type can be refined to measure the crashworthy benefits for specific aircraft, equipment, and occupant factors.

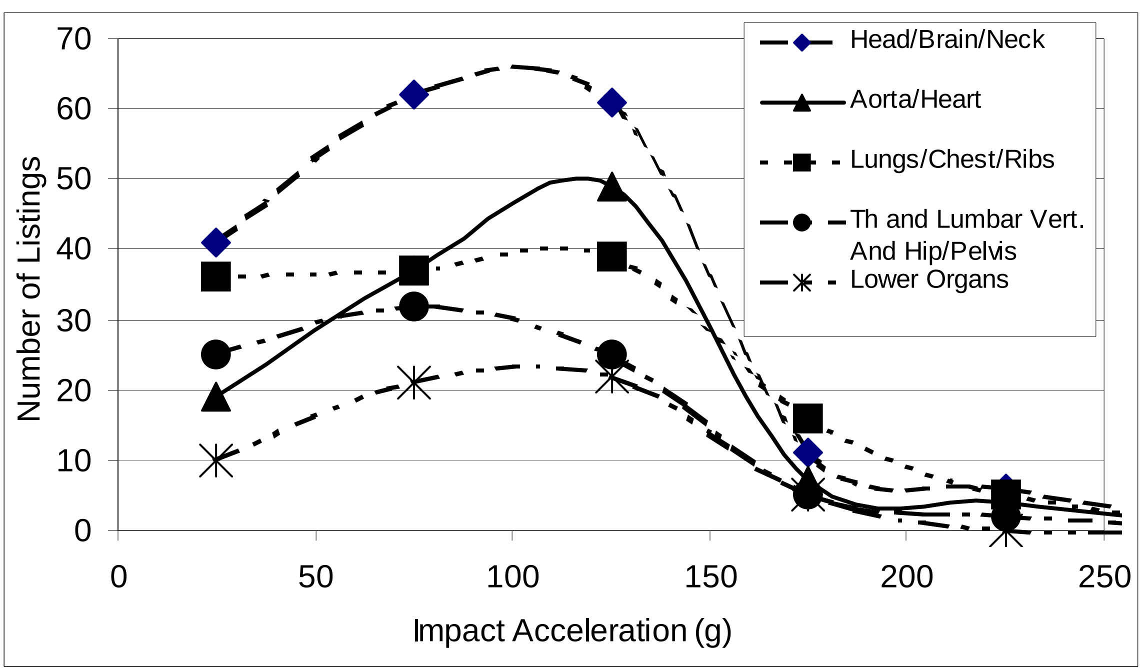

Figure 5. Injury Listing vs Impact Resultant

Conclusions

Evaluations of injury patterns relative to accident parameters provide a basis and perspective for measuring crashworthy design progress. Improved data collection and access to survival factors investigations for small civil aircraft are needed to evaluate crashworthy design. Current accident data does not provide the means to perform cost benefit analysis or prioritize crashworthy design in the future.

Regarding the rotorcraft accidents in general, all impact orientations are significant. The impact acceleration forces in all directions should be considered when evaluating the potential for occupant safety, unless factors specific to the aircraft type or mission can be used to narrow the focus.

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Biography of the Author

Mr. Barth graduated from Colorado State University in 1989 with a Bachelors in Mechanical Engineering, and is currently writing a Thesis for a PhD by Research at Cranfield University. He has 17 years experience in automotive and aircraft restraint system development and vehicle crash dynamics. Mr. Barth is the Director of Research and Development and Accident Investigator for Amsafe Aviation.

Appendix: Complete Injury Listing

Above Shoulder	All	Fatal	Non-Fatal
Head/Skull/Brain	551	462	89
HEAD (UNQ)	56	44	12
BRAIN	160	130	30
FOREHEAD	12	3	9
FRONTAL	7	3	4
MULTIPLE BONES (CALVARIUM)	9	9	0
SKULL	153	149	4
TEMPLE	3	1	2
SCALP	7	1	6
Neck	72	61	11
ATANTO-OCCIPIAL	9	9	0
MULTIPLE BONES (BASILAR)	20	20	0
LARNYX	3	3	0
NECK (UNQ)	27	16	11
OCCIPITAL	5	5	0
TRACHEA	8	8	0
Face/Jaw	132	45	87
CHIN	11	1	10
EYES	15	1	14
FACE (UNQ)	32	14	18
ORBIT	4		4
TEETH	6	1	5
JAWS	5	1	4
LIPS	7	0	7
MANDIBLE	9	6	3
MAXILLA	5	1	4
MULTIPLE BONES (FACE)	19	18	1
NASAL	12	1	11
ZYGOMA/MALAR	7	1	6
Vertebra	50	38	12
VERTEBRA C1	16	16	0
VERTEBRA C2	8	5	3
VERTEBRA C3	7	6	1
VERTEBRA C5	4	0	4
VERTEBRA C6	8	6	2
VERTEBRA C7	7	5	2

Upper Torso	All	Fatal	Non-Fatal
Chest	301	254	47
CHEST (UNQ)	74	62	12
LUNGS	122	106	16
RIBS/SIDES	95	80	15
STERNUM	10	6	4
Vertebra	77	48	29
VERTEBRA T1	8	8	0
VERTEBRA T2	3	2	1
VERTEBRA T3	7	6	1
VERTEBRA T4	9	6	3
VERTEBRA T5	6	6	0
VERTEBRA T6	7	6	1
VERTEBRA T7	4	1	3
VERTEBRA T8	5	2	3
VERTEBRA T10	4	2	2
VERTEBRA T11	8	2	6
VERTEBRA T12	12	4	8
VERTEBRA, MULTI-THORACIC	4	3	1
Heartt/Aorta	250	249	1
AORTA	124	124	0
HEART	123	122	1
VENA CAVA	3	3	0

Lower Torso	All	Fatal	Non-Fatal
Hip/Pelvis	100	82	18
HIP	5	1	4
PELVIS (UNQ)	93	80	13
SACRUM	2	1	1
Lower Organs	202	172	30
ABDOMEN (UNQ)	44	38	6
BLADDER	4	1	3
DIAPHRAGM	14	12	2
GENITALIA	3	1	2
INTESTINES (UNQ)	7	4	3
KIDNEY	15	10	5
LIVER	61	59	2
PANCREAS	4	4	0
RECTUM/ANUS	2	2	0
SPLEEN	46	39	7
STOMACH	2	2	0
Vertebra	77	18	59
VERTEBRA L1	23	5	18
VERTEBRA L2	24	5	19
VERTEBRA L3	9	2	7
VERTEBRA L4	6	0	6
VERTEBRA L5	3	0	3
VERTEBRA, LUMBAR	12	6	6

Upper Ext	All	Fatal	Non-Fatal
Upper Extremities	171	87	84
THUMB	3	1	2
CLAVICLE	17	10	7
ARM LOWER (UNQ)	53	30	23
ELBOW	11	3	8
FINGER	6	1	5
HAND (UNQ)	17	8	9
SHOULDER	17	4	13
SCAPULA	8	2	6
UPPER EXTREMITIES (UNQ)	28	25	3
WRIST	11	3	8

Lower Ext.	All	Fatal	Non-Fatal
Lower Extremities	253	119	134
HEEL	1	0	1
FOOT (UNQ)	18	6	12
ANKLE	31	3	28
LEG LOWER (UNQ)	110	51	59
LEG UPPER (UNQ)	53	35	18
LOWER EXTREMITIES (UNQ)	28	24	4
KNEE	12	0	12