CHARACTERIZATION OF ROLLOVER CASUALTIES

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ABSTRACT

The authors have examined data from the National Accident Sampling System (NASS) to determine the factors in the crash which increase the severity of harm to the occupant. This paper describes the results to date. The mean speed for rollovers is found to be much higher than for planer crashes. Vehicle speed is an important predictor of injury outcome. However, imprecision in coding the speed and the vehicle damage detract from the ability to use these variables for injury prediction. Data collection improvements are suggested.

INTRODUCTION

Rollover crashes are extremely harmful events. Each year, in the United States, rollovers cause nearly 10,000 fatalities, and 30,000 serious injuries.

The injury mechanisms in rollover are not well established. There are no federal standards which require crash tests in the rollover mode. In past years, federal safety research has focused on frontal and side crash protection, at the expense of rollover. Consequently, data collection elements, laboratory test facilities, and crash injury countermeasures have been oriented toward planer crashes. In many cases, rollover crashes have different and more demanding requirements.

The complexity of rollover events make the characterization of these accidents much more difficult than for planer crashes. For planer crashes, delta v has been widely accepted as a measure of the crash severity. Techniques and computer analyses are available for estimating planar crash severity, based on energy dissipation from the observed vehicle damage or post crash trajectory. There is no similar accepted estimate for rollovers accident severity.

Past studies of rollover crashes suggest that the initial speed, number of quarter turns, extent of damage, and characteristics of the tripping mechanism are significant accident parameters which influence the severity of the occupant/vehicle interactions and the resulting outcome. The characteristics of the vehicle - by type, wheelbase, track width, and center of gravity height have been reported to influence rollover frequency.

Within this diversity of influencing factors, safety engineers need to assess the efficacy of occupant protection countermeasures. Further, a basis for selecting test procedures, and relating compliance with these procedures to benefits is vitally needed.

The safety countermeasures to reduce rollover casualties include the following: improved safety belt systems, interior padding, improved door integrity, increased roof strength, and improved window design for occupant containment. The benefits assessment for these countermeasures presents a challenge.

The problem of assessing countermeasures in rollover is confounded by the lack of dummies, laboratory test facilities, and test procedures to study rollover. There is no rollover test dummy which has been validated in a manner analogous to the Hybrid III in frontal, or the SID in side impacts. Similarly, there is no laboratory facility in rollover that is equivalent to the crash test sleds used in planar impact research. Rollover testing has relied principally on full vehicle rollover tests with their attendant expense and variability. There are several full vehicle rollover test procedures currently in use, and the relationship between them is undetermined. The lack of rollover dummies, test facilities and test procedures underscores the need for research to better characterize rollover, assess the benefits of alternative countermeasures, and define practical testing and measurement requirements.

The authors are engaged in examining rollover crash data from the National Accident Sampling System (NASS), to develop a semi-empirical characterization of rollover. Our objectives include the identification of parameters which are practical and useful for defining the severity of a rollover crash. In addition, we are examining the field experience to determine the distributions and sources of occupant injuries as related to "rollover severity", and other pivotal parameters. Finally, we are examining the "hard copy" documentation of rollover cases to assess ways of defining and coding the data elements needed for rollover analysis.

PAST RESEARCH

A number of studies of rollover accident data and vehicle testing are reported in the literature. These studies use several different accident data files maintained by the National Highway Traffic Safety Administration (NHTSA) in the United States. The Files include the following: (1) NCSS, the National Accident Sampling System, a file of tow-away crashes collected between 1975 and 1977. (2) NCSS, the National Accident Sampling System, a similar file of more than 100,000 police reported crashes between 1977 and 1986, and of tow-away crashes between 1988 and the present. (3) FARS, the Fatal Accident Reporting System, a census of traffic fatalities from 1975 to the present, (4) Cardfile, a file of more than 4,000,000 police reported crashes from six states during a recent four year period. (5) Cars, a file of police collected data on 3,000 rollover cases in the State of Maryland.

Some of the most relevant conclusions from past research studies will be described in the paragraphs to follow.

McGuigan and Bondy [1a] studied the NCSS and FARS data to assess accident, vehicle, and injury characteristics. The authors found that the risk of serious injuries and of ejection were much higher in rollovers (11.5% vs. 4.1%; and 7.8% vs. 0.6%, respectively). The head and neck were the most frequent serious injuries. Injury severity was found to be related to number of quarter turns and distance traveled.

Najjar [1b] compared NCSS crashes partitioned into three categories: "Pure" rollover, Impact then rollover, and Non- rollover. The probability of injury for the three categories were: .085, .103, and .042. Among the impact then roll cases, 45% sustained frontal damage, and 22% sustained side damage.

McGuigan [1c] proposed a three level accident severity scale for "pure" rollover based on roof crush as defined by the Collision Deformation Classification (CDC), and number of rolls. The proposal was based on NCSS data. Level 1 consisted of a CDC of 3 or less and a rolls/roof crush of 4 or less. Level 3 was defined by a CDC of 4 or more and a rolls/roof crush of 5 or more. Level 2 was defined by the intermediate gap. The injury probability associated with the three levels was .029, .115 and .358, respectively. Partyka [2] examined early NCSS data and found that rollover and ejection are each independently associated with a higher rate of fatality. Ejection and rollover increase the fatality odds ratio by a factors of 34 and 2, respectively.

Segal [3] studied the accident case files of 267 severe rollover accidents in the National Crash Severity Study (NCSS). The NCSS [4] files are based on case investigated from 1977 to 1979. Accidents were selected for case by case review, based on the presence of door opening, and/or significant roof crush. The cases studied were predominantly (89%) passenger cars. For about half of the cases, the pre-crash speed was estimated to be greater than 50 mph. Segal observed that most rollover accidents involved some degree of skidding sideways prior to rollover. About 80% of the vehicles had a lateral velocity component before the rollover occurred, and most had a significant forward component as well. The overturning motion was primarily roll motion in 80% of the cases examined. About 15% of the vehicles had primarily pitch motion, and the remaining 5% combined pitch and roll. Most of the vehicles rolled four quarter turns or less. Segal noted that high injury severity to occupants appeared to be related to the number of quarter turns experienced by the vehicle. Door opening and ejection also appeared to increase with the number of quarter turns, which may account for the higher injury severity. The degree of roof crush was relatively independent of roll turns.

To learn more about factors influencing rollover and ejection, Terhune [5] examined single vehicle crashes involving 4,565 vehicle from the combined 1980-85 NASS file. As part of his study, he created a "clinical file" of 402 single vehicles crashes which included 192 rollovers. He found that a side force tripping phenomena preceded approximately 65% of passenger car rollovers and 85% of LTV rollovers. In controlling for crash severity, Terhune used the extent of roof crush, as defined by the Collision Deformation Classification [6]. He found that, for passenger cars, ejection rates and injury rates for those not ejected generally increased with increasing top damage measured by CDC. Terhune concluded that ejection is very dangerous to occupants, even in low severity crashes.

Malliaris [7] analyzed ejections and non-ejections reported in FARS between 1975 and 1985 and found that the odds of fatality for car ejectees are six times higher than for non-ejectees subjected to very similar crash conditions, irrespective of seating position. The fatality odds for light truck and van ejectees are 25% higher than for car ejectees.

Cohen et.al. [8] examined single vehicle longitudinal rollover cases reported in NASS 1981-86. He found that rollover frequencies were related inversely to vehicle size class for cars and pick-up trucks. The analysis suggested that the primary area of damage and extent of roof crush were good indicators of injury for restrained and unrestrained non-ejected occupants. For ejected occupants, number of quarter turns was an additional indicator variable. Ejection from two door cars was twice as likely as ejection from four door cars.

Papers dealing two different types of full scale car rollover tests have been reported by Habberstad, et.al. [9] and Orlowski, et. al. [10]. The Orlowski paper documented pure roll tests of Chevrolets with and without roof reinforcement. The authors concluded that a roll cage did not reduce injury measures on a test dummy for the vehicle and roll condition tested. The Habberstad paper reported full vehicle testing which involved severe tripping prior to the roll. The tests showed that severe dummy impacts with the vehicle interior could be induced early in the rollover event.

Robertson [11,12] found that fatal rollover of utility vehicles per 100,000 registered vehicles relative to cars during 1982-87 was strongly correlated to the static stability of the vehicles. Brewer and Harwin [13] examined vehicle, driver and environmental factors which could be deduced from Cardfile and found that vehicle stability factor (a ratio of the track width and center of gravity height) had a strong influence on rollover involvement risk.

Malliaris [14] examined FARS and Cardfile to determine the significance of motor vehicle characteristics on rollover propensity, After controlling for nonvehicular influences, he found that wheelbase and stability factor were both influential.

Mengert, et. al. [15] examined the single vehicle rollover risks for 40 vehicle make/models in the states of Maryland, Texas, and Washington. Vehicle stability factor and urban/rural location were found to be important predictors of rollover risk. Harwin and Emory [16] examined the CARS data for pre-crash conditions. They found that 80 to 90% of the rollovers were tripped, generally by soil. They reported that injury severity correlated strongly with speed. Stability factor, and number of quarter turns were also influential.

ROLLOVER CHARACTERIZATION

To provide a perspective on parameters which influence rollover outcome, selected parts of our analysis of 1985-86 NASS data are presented.

Designated as "Harm" in this investigation is a weighted sum of fatal outcomes and survived injuries in any given population of crash involved people. The weights in the summation are scaled in accordance with the economic and other costs of injuries incurred in crashes and the severity of the associated outcomes.

Specifically, in applying the harm concept we aim at summing up all injured people, each weighted in proportion to the severity of the outcome of the person's most severe injury, irrespective of property damage.

Because of the complexity of the subject, the quantification of injury outcomes and the assignment of economic and other costs to such outcomes is still tentative. This is especially true when a comprehensive coverage is desired of all injuries, irrespective of category, severity, and complexity of consequences.

A review of the relevant literature reveals many specialized investigations, concerning specific human body regions or organs, injured at specific severities. However, there are only two studies that address the entire spectrum of injured body regions and injury severities.

The first and earlier study, conducted by NHTSA [17,18], distinguishes between fatalities and injured survivors by severity, without offering any resolution concerning injured body regions. This study addresses all components of economic costs to society including: productivity losses, medical and hospital costs, legal costs, insurance expenses, property damage, and other. It excludes the less tangible costs such as pain and suffering.

The second study, by Miller [19,20], covers all the cost components addressed in the NHTSA study but with the following two extensions: (a) resolution by injured body region or injured organ, and (b) a consideration and quantification of "Pain and Suffering" costs. Both the Miller and the NHTSA studies are sufficiently disaggregated, so that the user may include or exclude cost categories depending on the specifics of the application at hand.

For the purpose of this investigation we adopted all cost categories included in the studies mentioned above, except property damage costs. The reason for this exclusion is that in applying the harm concept we aim at summing up all injured people, each weighted in proportion to the severity of the outcome of the person's most severe injury, irrespective of property damage.

The Miller costs also include a category, "Pain and Suffering". We have conducted analyses with and without the inclusion of "Pain and Suffering". As it turns out, the analyses yield very comparable results, when the purpose is to evaluate harm distributions among (as opposed to absolute harm values associated with) various values assumed by variables of interest in this investigation. Thus for simplicity we have excluded "Pain and Suffering" in our harm evaluation. The resulting Harm Schedule is shown in TABLE 1.

In comparing rollover and planer cases in NASS, we find profound differences. Ejections account for more than 60% of the harm in rollovers, compared with less than 20% in planar crashes. The ejection harm is expected to decrease significantly as the use of safety belts increases.

The distribution of crash speed for rollovers is significantly different from planar crashes. This difference is shown in Figure 1. For planer crashes, the travel speed is less than 40 mph in 80% of the cases. By comparison, approximately 60% of rollovers occur at travel speeds between 40 and 60. A significant number occur at speeds greater than 60 mph.

Examination of the independent variables associated with rollover can be aided by three parameters which provide a quantitative perspective. These are: 1) the occupant exposure, 2) the harm, and 3) the relative harm per occupant. The occupant exposure is the relative frequency of car crashes, as a function of general rollover parameters. The harm is a convenient way of quantifying the frequency and severity of injuries. For the analysis presented here, both quantities are evaluated as a percentage of the total for the specific crash parameter under evaluation. The relative harm per occupant is the harm percentage, divided by the occupant exposure percentage. Harm per occupant provides an indication of the severity of a class of events relative to injury outcome.

These parameters are shown in TABLE 2 for five different rollover parameters which influence outcome. The parameters are: Travel Speed, Number of Vehicles Involved, Occupant Ejection, Axis of Vehicle Rotation, and Number of Quarter Turns.

The relative harm per occupant can be used to illustrate the importance of travel speed on injury severity. TABLE 2 shows car occupant exposure and harm as a function of travel speed. The analysis shows that both exposure and harm are largest in the 40-60 mph speed range. However, as speed increases, the harm increases rapidly, relative to the exposure. The effect of speed on relative harm per occupant is shown graphically in Figure 2. The relative harm per occupant increases dramatically with speed. Speed is one of the pivotal parameters which characterizes the rollover severity relative to injury outcome.

Other rollover parameters are shown in TABLE 2. A number of observations can be made from the data presented. Single vehicle rollovers account for more than 80% of both exposure and harm, relative to rollovers involving multi- vehicle crashes. Ejection constitutes a 10% of the exposure but 60% of the harm. Over 90% of the exposure and harm are associated with motion about the roll rather than pitch axis. However, the harm per occupant is much greater for those small numbers involving pitch motion.

TABLE 2 also shows a comparison of rollovers involving different ranges of quarter turns. Four quarter turns are equal to one complete revolution of the vehicle. Nearly 70% of the vehicles involved in rollovers turn less than one complete revolution. Harm is about equally distributed between the two groups. Relative harm per occupant is about twice as high for the 4+ group.

INJURY DISTRIBUTIONS

We have examined the distribution of injuries and the source of injuries to occupants involved in rollover crashes. The 1988-89 NASS file is useful for this purpose because it contains a higher proportion of restrained occupants than the NASS files from earlier years. In the 1988-89 file, 48% of those injured were restrained. However, restrained occupants accounted for only 22% of the harm. The mean severity of injuries to restrained occupants was significantly less than to those who were unrestrained.

The distribution of harm by body region is shown in Figure 3. The data presented includes occupants of passenger cars in all seating positions. It excludes occupants who were totally ejected. The two restraint categories are presented - restrained occupants, and unrestrained occupants who were retained in the vehicle during the rollover. The harm in each of the two categories totals 100%. The distributions shown provide a comparison of the relative distributions of harm for restrained and unrestrained (retained) occupants of passenger cars in rollover crashes. Injuries to the head and trunk predominate for both restrained and unrestrained occupants. The most significant change is the higher proportion of harm to the neck suffered by restrained occupants.

The principal sources of the injuries to rollover crash victims are shown in Figure 4. The data for this figure was developed in a similar way to that of Figure 3. The use of restraints significantly reduces the proportion of harm caused by the windshield, dashboard and steering system. The upper structure and exterior account for about the same harm fraction in each group. Sources of increases in harm proportion for restrained occupants are the lower side, "other" interior components, and non-contact. "Other" interior components includes restraint systems which are the principal source of the increase. Non- contact injuries include injuries from flying glass, burns, etc. The components which offer the greatest opportunity for injury abatement to restrained occupants are: the steering system, the upper and side structure, "other" interior components (including restraint systems), and the side structure.

IDENTIFICATION OF DATA COLLECTION IMPROVEMENTS

Two pivotal parameters which characterize single vehicle rollover severity are initial vehicle speed and extent of damage. In examining hard copy NASS cases we found a need for algorithms to more precisely define and quantify these parameters.

In the case of initial speed, the basis for the estimate was generally a police officers judgement. The speed variable was not coded in 40% of the cases. Clearly, an objective algorithm based on energy considerations is needed. Such an algorithm is under development, and will be applied to all 1988-89 NASS rollover cases. A reanalysis of the resulting data will determine the extent of the bias introduced by the present uncertainty of the speed variable.

In the case of vehicle damage, we found that the Collision Damage Classification for the vehicle top lacked the precision needed for rollover analyses. The present algorithm measures all damage to the upper part of the vehicle from a waterline positioned at the top of the roof. Consequently, CDC does not measure equivalent damage to different parts of the vehicle's upper surface. For example, a CDC of 6 represents only minor damage to the trunk and hood, but complete collapse of the vehicle roof. Consequently, small deformations in the hood and trunk carry the same deformation coding as very large deformations in the roof. In some rollovers, the top is undamaged, but the trunk or hood are significantly damaged. These cases would be coded as a top CDC of 6 or more. Such an inaccuracies make it difficult to use the NASS files to assess the hazards of roof crush. We have proposed a revision to the CDC based on experience gained by one of the authors in investigating rollover crashes in South Australia.

SUMMARY AND CONCLUSIONS

Rollover crashes claim nearly 10,000 lives in the United States, annually. They continue to pose a serious threat. Dummies, test procedures and test facilities for rollover have not reached the level of sophistication of those for side and frontal crashes. The complexity of the rollover event, and the limited means of evaluating rollover safety improvements has hampered advancements in occupant protection technology.

Car rollovers are predominantly single vehicle events. They generally (97% of the time) exhibit a roll rather than a pitch motion.

Car rollover crashes differ from all other crashes rather profoundly in virtually all respects: key crash parameters, intermediate outcomes, especially ejections, and final outcomes.

The travel speed distribution for rollovers is quite different from planer crashes. Rollovers tend to occur at higher speeds.

Car travel speed is a primary determinant of intermediate and final outcomes in rollover crashes.

Restraint systems are highly effective in reducing harm in rollovers. In the 1988-89 NASS files, 48% of the occupants were restrained. They suffered only 22% of the harm.

The head/face, and trunk (chest, abdomen, pelvis, and shoulder) injuries constitute about 65% of the harm for restrained occupants. Neck injuries comprise about 15%.

Analysis of the percent harm to occupants in rollovers in terms of body regions indicate the predominance of head/face and neck injuries for both restrained and unrestrained subjects. A most significant finding is an increased percentage of harm to restrained occupants for neck injuries as opposed to head injuries. The dichotomy of the protective effect of restraints is reminiscent of an earlier finding by one of the authors in collaboration with Langweider et. al. [21]. This research showed that in frontal crashes, restrained occupants have a higher incidence of neck strains (AIS 2-3) but a lower incidence of AIS 4 - 5 neck injuries and head injuries of any significance. These results suggest continued needs to further reduce neck loading among restrained occupants in both frontal and rollover crashes. Obviously, more detailed studies with adequate models are essential.

The steering system, upper structure, lower side, and "other" interior components (including restraints) are the greatest sources of harm to restrained occupants. Each of these four categories accounts for more than 15% of the harm.

The data elements coded in the National Accident Sampling System (NASS) the lack precision needed to evaluate two parameters which are pivotal to rollover outcomes. These parameters are speed and extent of top damage. Improved algorithms for these parameters are under development.

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TABLE 1

HARM WEIGHTING FACTORS

PROPERTY DAMAGE, PAIN & SUFFERING EXCLUDED

	BRAIN	SPINAL	FACE*	TRUNK	UPPER X	LOWER X
SURVIVED AIS 1	4		4	3	4	3
SURVIVED AIS 2	16		19	16	28	28
SURVIVED AIS 3	68	105	88	45	66	84
SURVIVED AIS 4	180	905	103	73		124
SURVIVED AIS 5	636	1,082	211	106		
FATAL	644	644	644	644		

AFTER MILLER, REF.19

* INCLUDES MINOR HEAD & NECK INJURIES

TABLE 2

OCCUPANT EXPOSURE AND HARM DISTRIBUTION IN ROLLOVERS – 1985-86 NASS

	OCCUPANTS %	HARM %	RELATIVE HARM PER OCCUPANT
**TRAVEL SPEED			
0-40	26.2	11.5	0.44
40-60	60.2	50.6	0.84
OVER 60	13.6	27.9	2.79
**NR. OF VEHICLES			
SINGLE VEHICLE	86.6	84.5	0.90
MULTI-VEHICLE	13.4	15.5	1.10
**EJECTION			
NO	89.9	38.1	0.40
YES	10.1	61.9	6.10
**ROTATION AXIS			
ROLL	97.1	93.1	0.90
PITCH	2.9	6.8	2.40
**NR. QUARTER TURNS			
ONE	18.1	12.4	0.69
2 OR 3	48.7	35.7	0.73
4 OR MORE	33.2	51.9	1.56

Figure 1
DISTRIBUTION OF CRASHES BY SPEED
1985-86 NASS

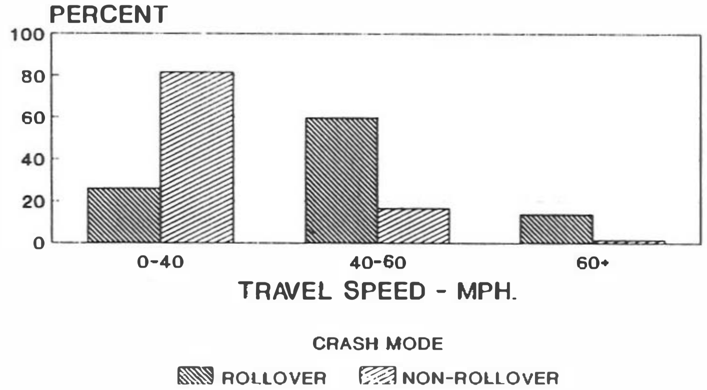

Figure 2
RELATIVE HARM PER OCCUPANT
ROLLOVER CRASHES - 1985-86 NASS

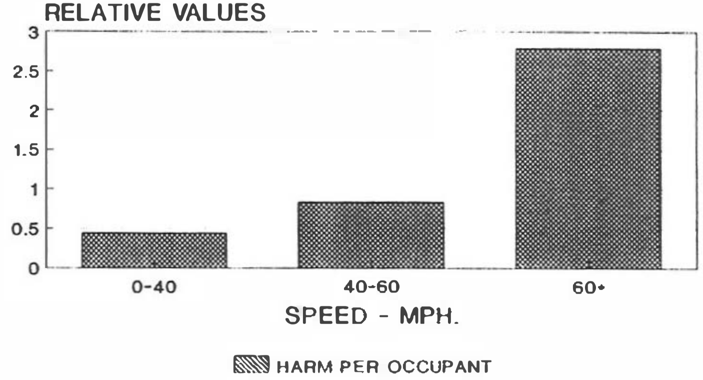

Figure 3
DISTRIBUTION OF ROLLOVER HARM
1988-89 NASS

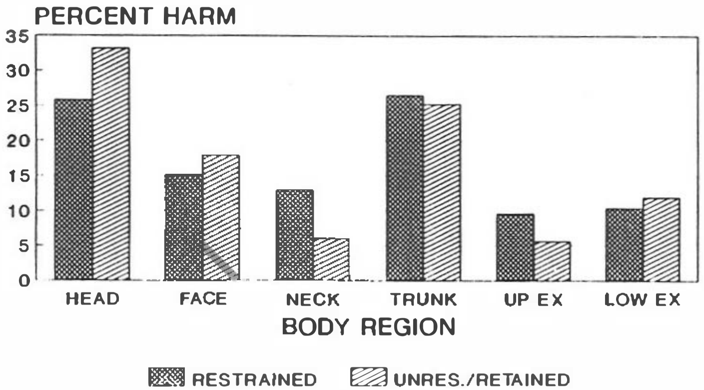

Figure 4
SOURCES OF ROLLOVER HARM
1988-89 NASS