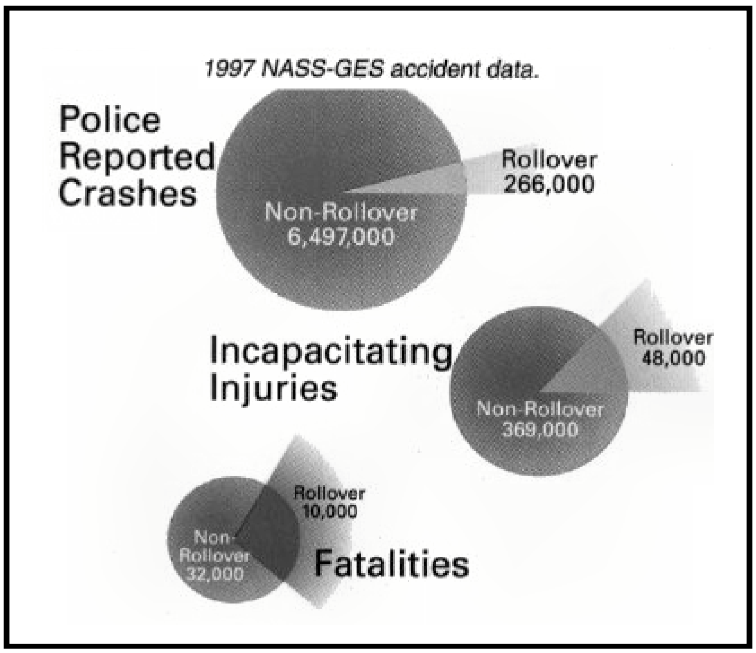
The Causes of Injury in Rollover Accidents

By Robert C. Eichler, TECHNICAL SERVICES, Vancouver, WA.

(from the *Accident Reconstruction Journal* -Jan/Feb 2003)

Rollover accidents are now responsible for almost 1/3 of all highway vehicle occupant fatalities as is shown in the chart below. Note also that the incidence of fatalities is about 1 per 27 rollover accidents. Rollovers tend to be more serious than other types of accidents. For light trucks and SUVs the percentage of occupant fatalities associated with rollovers is about 50%. For heavy trucks the number is about 60%. Yet despite the long-standing seriousness of the problem there is still no consensus on the causes of injuries in rollover accidents.



Discussions of rollover injuries frequently take notice of the phenomenon of ejection and the prevalence of ejections among occupants who are seriously hurt or killed in rollover accidents. But let us note here that ejection is not in itself an injurious process. It is not a mechanism of injury. Rather, ejection represents an opportunity to experience another potentially injurious process, e.g., ground contact. Occupants are ejected because they are not restrained by the vehicle. They sometimes experience harmful effects because of this fact; but lack of contact with the vehicle (on the way out) is not inherently harmful. The question of the importance of ejection in rollovers is also complicated by the fact that it is sometimes difficult to determine whether the injuries were suffered before or after the victim left the vehicle. Perhaps the most important ejection related question is whether or not there is any reason for an occupant to be ejected from anything other than an opening in the vehicle that was there <u>before</u> the rollover. We address this question below.

What then are the causes of injury for non-ejected occupants in rollover accidents? It is now generally agreed that the predominate mechanism is impact and not crushing as has sometimes been thought in the past. This at least for light vehicles (here light vehicles means under 10,000 lbs). The case with heavy trucks is probably different as we shall see later however. We should then try to clarify the differences between these two processes. Impacts are of relatively short duration and involve only the striking and the struck objects. Crushing suggests a slower process involving the crushed object and two other surfaces or elements between which the object is crushed. Crushing can take all day, even a slow impact is still a relatively quick bump or bang. The point is that we should not expect to see and typically do not see a "tail print" in the floor pan of every rolled vehicle in which an occupant is seriously injured. Light vehicle occupants are not typically squeezed between the roof and the floor, nor do they generally suffer any other type of crushing injury, they are hit. They experience a "second collision" like some victims of planar accidents.

But what then is the process by which serious "second collision" injuries are produced in rollover accidents?. The origin of impact injuries does not at first seem to be obvious. Rollovers, unlike vehicle to vehicle collisions are basically low "g" affairs. Rollovers, unlike planar impacts, are self-limiting, the vehicle goes over as soon as it can. When the upsetting force is high enough, the wheels lift. If the upsetting influence persists long enough, the vehicle rolls over. Unless the vehicle experiences a change in elevation, no more energy can be put into the system after the rollover impulse terminates and this impulse is itself determined largely by the geometry and weight of the vehicle. There are exceptions to this, for example when a vehicle is induced to rollover by a collision with another vehicle, but generally the initial rollover kinematic and dynamic parameters are defined and limited by the vehicle itself. Contrast this with, say, a barrier accident. How severe is a barrier accident? How fast are you going when you hit the barrier?

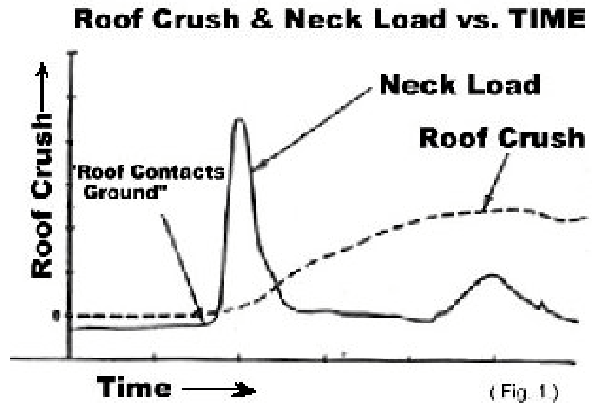
Accident reconstructionists typically use a deceleration rate of about 0.4 – 0.5 g's for rollover accidents. But this is just an average over a rather prolonged series of rolling, sliding and banging events. The bangs or impacts are what is of interest here and they seem to typically be about 10 g's (See reference 6. for example) Now 10 g impacts should be sustainable without serious injury unless the blow is concentrated on a very small area. Ten g's on the head for example is only about 140#- 150#. It depends, off course, on what exactly the loading process is like, but the literature does not seem to support the view that the harm generated by rollover accidents is the result of 10 g blows.

THEORIES of the INJURY MECHANISM

Higher forces and related mechanical influences are needed for broken heads, broken necks and other serious rollover injuries. There seem to be two contrasting theories on how these injurious effects develop in rollover accidents. One position, which seems to be favored by large segments of the automotive industry, holds that there is a “drop” or a “fall” or a “dive” associated with rollover accidents that is the chief (only?) cause of injury for non-ejected occupants and concurrently, that roof crush is irrelevant. Another view held by some highway safety advocates and certain experts holds that “roof crush” or more generally the failure and displacement of the vehicle’s greenhouse (glass and related supporting structures) is the cause of injury in rollovers.

Anyone who has examined a rolled vehicle of domestic or Asian design has probably observed extensive roof crush or greenhouse damage and displacement. That this phenomenon exists is easily seen. It is not however as obvious that the occupants of rolled vehicles were “dropped” or that they “fell” or “dove” during the rollover that produced the damage. Vehicle occupants change elevation relative to the ground during the course of a rollover. They maybe lifted by the rollover event and then lowered as the vehicle touches down, but a change in elevation is not necessarily a “drop”, “fall” or “dive”. These three terms all denote unrestricted (mostly) vertical motion under the influence of gravity alone. There is little evidence that this occurs during highway rollovers of light vehicles. Occupants of light vehicles are rolling with the vehicle and are in at least intermittent contact with the vehicle during the course of the rollover even if unbelted. Bouncing and rolling down a hill are not the same as falling off a ladder or diving into an empty swimming pool. The use of terms like “fall”, “dive” and “drop” by technical experts discussing rollover amounts to a gratuitous poetic license unless it is backed by analysis in a particular case. As a generic description of events it is at best misleading.

The proponents of this elevation change or “height” theory of rollover injuries claim their views are supported by more than just metaphor however. Specifically, they claim two general sorts of support, statistical and experimental. Let us first consider the experimental evidence. The most commonly cited example is the Malibu series of rollovers and related tests. The Malibu series was sponsored by General Motors. It involved dolly rollover testing and drop testing with instrumented dummies in 1983 Malibu sedans with both stock and reinforced roofs. A much-promoted result of these tests is illustrated in Figure1. The dummy in this representative instance experienced the highest neck loads when the roof struck the ground, before the roof collapsed.



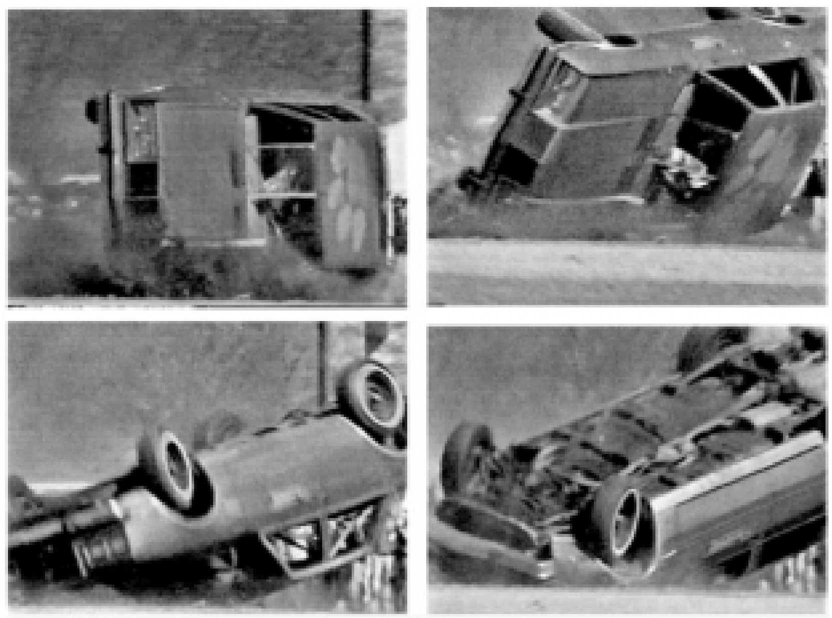
(Following Moffatt et all in SAE 902314)

In spite of a lack of demonstrable relevance to highway rollovers, the authors of papers advocating the theory in question have not been modest in their claims about the results of their extremely limited testing programs. “The results of this work indicate that roof strength is not an important factor in the mechanics of head/neck injuries in rollover collisions for unrestrained occupants.” (Reference 1. -Abstract) In a subsequent series of tests using belted dummies, the question of the relevance of roof crush becomes a little more ambiguous, except for belted dummies remote from the area where the roof contacts the ground because the belt may keep these occupant surrogates from actually coming in contact with the roof in areas where the roof does not deform.

In another paper (reference 2.) Habberstad et. all. roll a 1975 Ford sedan and determine that “Roof crush is not a factor in the injury mechanism for the *conditions simulated in this test.”* (italics are mine) (Conclusion 2.) Also that for “… an event of this type and severity…there is no correlation between roof crush and injury.” (Ibid., abstract). This test involved a driver dummy moving over into a left side roll. The dummy’s head hit the roof rail at 165 milliseconds into the event, but the roof deformation did not start until 1250 milliseconds At this time ”…the occupant was not in position to be effected by the structural deformation” (ibid. pg. 8.) This, as we shall see, is a significant admission.

The Malibu tests involved lateral rolls off a dolly with some yaw and about a 32 mph launch velocity. But this was a lateral velocity, not a forward velocity. The test vehicles did not have an appreciable forward or longitudinal velocity. This is a condition seldom if ever found in real world accidents. Most rolled vehicle have a significant longitudinal velocity component. They are moving forward even if not facing forward and not just laterally when they roll. This is important because the ground impact forces will act to oppose the vehicle total motion, and if there is no longitudinal component to the motion, there will be no longitudinal component to the impact force. Consequently the dummies in the Malibu tests were thrown up against the roof and side rail by centrifugal force and not forward into the “A” pillar with the first ground contact. Vehicle and occupant kinematics were thus not similar to those encountered in most real world accidents.

A more representative depiction of a highway rollover is illustrated below.



Notice that the complicated pattern of rotation, pitch, roll and yaw, some of which was produced by earlier ground contact; is determining the contact pattern of the greenhouse. The order and severity of ground contact of specific points on the vehicle, e.g., the corner of the fender, the roof at the “A” pillar, roof headers, is determined by these parameters as well as the geometry of the vehicle. Long hood, low roof cars are going to hit different than minivans, for example, even given similar initial rotational velocities profiles. Moreover, subsequent impacts and roll kinematics will be influenced by what happens during prior impacts. A vehicle whose roof collapses will have a different geometry and may roll differently than a vehicle that remains intact. Naturally, the occupant kinematics will reflect what is happening to the vehicle. Even if they are belted, the occupants motion is not easily defined or determinable given the variability of their initial conditions and the complexities of their interaction with the interior. All occupants will respond to the centrifugal forces associated with the vehicle’s complex rotation, they will tend to move up and out if high sided for example. But it is impossible to say more than this for the general case.

These considerations are relevant here because these three test series were conducted using only two vehicle models, both of which are rarely seen any more on American highways. Roll kinematics depend on vehicle dimensions and shape as argued above (See reference 8. also.) and none of the studies attempted to show that the vehicle used were in any way representative of the entire vehicle population either at the time they were done or today. Every year there are several hundred vehicle models available for purchase in the U. S. market involving probably over one hundred basic platforms. What basis do we have for thinking that tests conducted on two models and two platforms produce results that are in anyway representative of the installed fleet at any time, then or now? Rollovers are complicated chaotic events, they are difficult to reproduce. Vehicle manufacturers have used this idea for years to resist the idea that they should due rollover testing at all. It is hardly consistent to claim that the tests described here which attempt to explain a more complicated phenomenon than vehicle rollovers themselves, namely the injuries that occur when vehicles rollover, are adequate to give a definitive view on the issue, even for the vehicles tested.

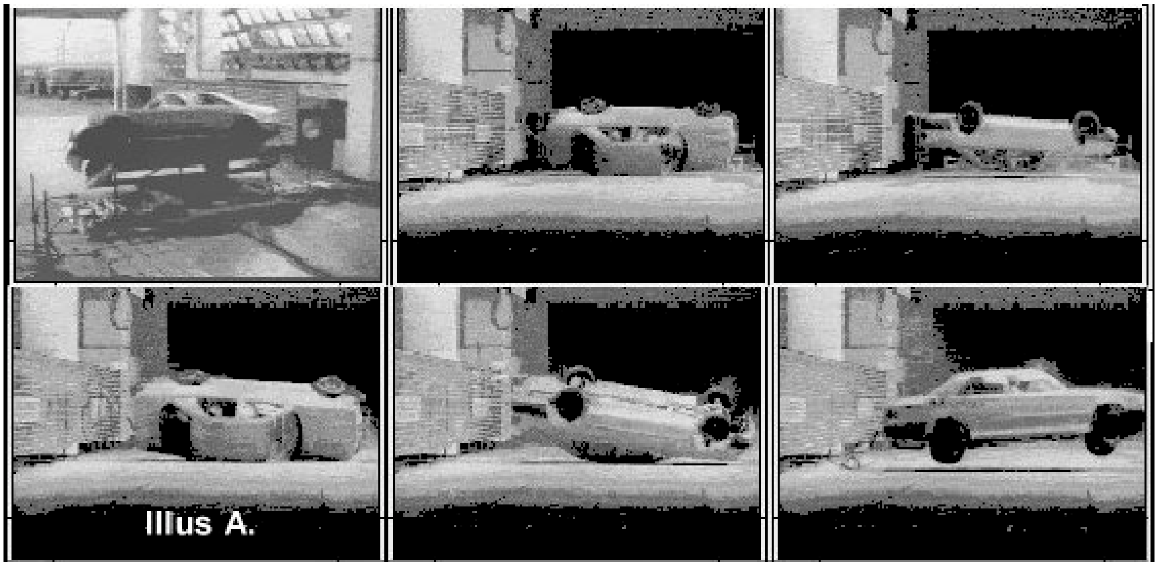
There are even greater problems associated with the use of the Hybrid III dummies employed in these tests Syson (reference 5) points out that these dummies have far stiffer necks than do cadavers, and thus live human occupants- some 10 to 50 times stiffer. This is important because the forces that develop during an impact process are determined by the stiffness of the impacting objects if everything else is held constant. Stiff neck dummies produce higher roof impact forces than would human being in the same circumstances. Hybrid III neck loads were about four times greater than those that would have been experienced by human beings according to Syson's analysis. Human beings experiencing the same event would thus probably not have suffered serious injuries. There is then no reason to think that the evidence of the Malibu series is relevant for human beings in real world rollovers either in terms of injury mechanisms or injury levels. The Malibu series, in fact, as will be shown below, does nothing more that illustrate some of the things that can happen when human beings are **not** seriously injured in rollover accidents. It does not constitute a explanation of the injurious process in rollovers, rather it is an illustration of some of the ways in which, on most occasions, serious injuries are avoided.

A second kind of evidence for the "height" theory is offered, proponents claim, by statistical data from rollover accidents. The statistics are commonly formulated on the basis of two different criteria, either maximum roof crush or the degree of compliance with FMVSS 571.216, the Federal roof crush standard for light vehicles. They are reputed to show that either increased roof crush makes no difference, or that variations in vehicle design relative to FMVSS 216 make no difference. Some studies are somewhat ambiguous with respect to the importance of roof crush or suggest that the issue is unresolved. (Reference 9. for example) Still others suggest that there is some evidence that very large crush values or crush beyond a certain level may be significant in terms of occupant outcome What the statisticians fail to explain is what if any difference any of this makes with respect to the fundamental question.

Supposedly, if roof crush is bad, more roof crush is worse, so that if we cannot establish that the degree of harm, or that the number of injuries or deaths correlates with the extent of roof crush, then roof crush is irrelevant. But this claim is a logical howler applied to a strawman argument. What's at issue in a rollover accident is whether or not the greenhouse fails, i.e., suffers structural damage sufficient to expose the occupants to serious harm. It is not obvious, nor need it be claimed, that the degree of failure or the extent of roof collapse is relevant. There is no reason to believe that collapse beyond some minimal critical value is important. Without a theory of how, specifically, the occurrence and severity of potentially harmful events, i.e., dangerous second collisions, are increased with increased roof damage the assumption is unwarranted or at best, suggests another, different, issue.

The chief problem with statistical arguments made from rollover data is there is no comparison to the null or zero case, those cases of serious rollovers where greenhouse failure does not occur. The few vehicles that do not have roofs that collapse in multiple roll accidents are not separated out in any data set with which the author is familiar. Most, if not all, published statistical analysis compares bad against bad with an arbitrary theory of what "worse" means. They do not contrast good against bad. What is needed are studies comparing FMVSS 216 vehicles to European vehicles whose roofs are far stronger than FMVSS 216 requires. European light vehicles do not have a mandated roof strength through common regulation. Subsequently many manufacturers use their own higher standard. We need analysis comparing Fords to Volvos, Chevrolets to (older) Saabs and Dodges to Mercedes before we draw statistically based conclusions on the roof crush issue.

Consider illustration A. (video captures from Mercedes test footage.) Note that the side glass does not seem to be fractured in the last frame. There is no evidence in the literature thus far cited to suggest that Mercedes is wasting money in making roofs like this, or that Volvo, or Saab or any of a number of other European manufacturers are likewise engaged in a fools errand when they design greenhouse structural integrity into their vehicles. Surely, the type evidence considered thus far is not enough to cause us to dismiss these efforts out of hand.



And if it is suppose to be enough, and roof crush is irrelevant, then why is it that the test Corvette used on the GM high speed test track is equipped with a roll cage? (Video capture below.)

Evidence from Heavy Vehicle Accidents

Though FMVSS 571.216 is of little or no value because the requirements are so minimal (see reference 3 for example), there is a Federal Standard that has been proven to reduce serious injuries in rollover accidents involving highway vehicle. FMVSS 571.220, at least as it has been implemented by manufacturers, has resulted in significant improvements in school bus safety. Consider the following case:

This Ohio school bus overturned after rotating 180 degrees while traveling about 35 mph. There were 37 children aboard at the time, all but one were treated and released with minor injuries. (See appendix A.) note that the roof “matchboxed”, that is, displaced laterally, but did not collapse significantly. The children’s heads were about 7’ off the ground at the start of the rollover. Those on the high side of the roll had their heads lifted further off the ground while the vehicle was actually rolling over of course. One would think that if the “height” or ‘‘drop” theories of rollover injury mechanics were correct that this would be an unusual outcome, virtually miraculous. Yet it is not. Despite a virtually complete lack of seat belts in school buses, despite the extreme elevation changes associated with these rollovers and the increased distance between the occupants’ heads and the roof, and despite the lack of padded roofs, non-ejected school bus occupants are very rarely if ever seriously injured in rollover accidents as a result of contact with the roof of the bus.

Exemplar School Bus Interior

Consider also this case:

This bus lost its brakes and rolled down a mountain in Colorado. One child was killed when ejected, another was seriously injured after a partial ejection. None of the children who remained in the bus were seriously hurt. The results of these two accidents seem to reflect the general situation with school bus rollovers (see reference 7.). They might in and of themselves cause us to disregard the types of theories of rollover injuries entertained thus far because evidence from more than fifty kids beats evidence from three dummies. But first we should consider still more evidence from another type of heavy highway vehicle.

Heavy trucks were almost completely exempt from Federal crashworthiness standards when they were first drafted, and still have little coverage. Importantly, there are no standards for cab structural integrity with respect to crashworthiness issues. As a result, about 60% of all driver (occupant) fatalities involve rollover accidents. But drivers in big rigs generally do not succumb to the types of mechanical trauma that kills light vehicle occupants, instead they most frequently die from positional asphyxiation. They cannot breathe because the weight of the tractor, pushing them into the ground due to the collapsed roof, prevents it. This takes about 10 to 15 minutes according to some eyewitness accounts. (It takes a diesel wrecker to turnover a big rig, they generally take too long to get to the accident site.) When they are finally pulled out and autopsied it is not infrequently found that the asphyxiated driver has little more than minor cuts and bruises, no broken bones or other serious injuries. Typical accidents and damage patterns are illustrated below:



One would think that if the subject theory of rollover injuries were true, then truck drivers who are higher off the ground than light vehicle occupants would suffer predominately from serious mechanical injuries in rollovers. But there is no evidence that this is the case. Most drivers are not seriously injured in rollovers unless the cab does a about a 180 degree roll resulting in almost complete cab collapse, they frequently walk away from 90 degree rolls to the right side despite all the “falls” and “drops” involved . But when the cab does collapse in on them, the most probable fatal injury mechanism is positional asphyxiation from the weight of the truck bearing down on them.

We should consider here another problem for all theories of rollover related injuries. An important problem for any theory is to explain why so few rollovers result in serious injuries or deaths. From the NASS –GES chart presented previously we see that, in addition to the fatalities, only about one rollover in six results in incapacitating injury. This is probably best explained in terms of occupant kinematics and the alignment and position requirements for head and neck injuries, as well the fact that most rollovers are less than 360 degrees, and that thus some occupants never contact the roof. But the general implication here is obvious, as argued previously, rollovers aren't inherently very severe or dangerous, they only become hazardous under certain conditions. The relevant question is then: Are there any vehicle related issues that increase the risk?

.

It should be clear at this point that the evidence for the "roof crush is irrelevant" theory is at best ambiguous. We should then ask if we are entitled to advocate it, even if we think it may be true, given the dire consequences of an incorrect theory and the lack of harm associated with adopting the alternative position. If the theory is wrong, then there are thousands of deaths and serious injuries that could have been avoided over the years with increased roof strength. Better to err on the side of caution, and build strong greenhouses as some European manufacturers do, than to take a chance and be responsible for the rollover carnage that has and is occurring on this nation's highways. Now, it has sometimes been suggested that roof crush is in fact not irrelevant but actually beneficial, and this idea perhaps could be viewed as a justification for both current design practice and the regulatory climate. But this notion has even less theoretical and experimental support than the "roof crush is irrelevant theory." Further, as we shall see below, this idea becomes irrelevant when we consider the problem of ejections.

The "dive", "fall", and "drop" theories were developed to support litigation and cannot be viewed as validated technical theories of the phenomenon they are posited to explain. Originally they were produced to oppose the plaintiffs "crushing" theories in rollover litigation. The Malibu series had the seat backs cut out so that it could be seen that the dummies were out of their seats for most of the rollover event. The chart presented earlier and the related theories about the relevance of roof crush were just "discoveries" that further served the interest of some defendants involved in litigation.

We have thus far been considering two issues without drawing a clear distinction between them. The first is the question of whether or not roof crush or as it has been called here, structural failure of the greenhouse, is in itself an injury producing mechanism. The second is the question of whether or not the phenomenon is tolerable regardless of the answer to the first question. The answer to this second question is obvious, greenhouse failure in rollover accidents is bad because it promotes ejection which puts vehicle occupants at additional risk in rollovers as noted previously. Kahane (reference 3.) reports that two thirds of the fatalities of car rollover accidents involve ejection. The standard remedy here is to invoke seatbelt usage, but there is, of course, another remedy. Namely: Don't allow openings in the vehicle to develop as a result of a rollover. The design standard for vehicle performance in a rollover should be this: *If there was no hole in the vehicle before the rollover then their should be no hole in the vehicle as a result of the rollover*. The Mercedes test illustration above suggests that this can be done, and there is no good reason not to do it

These openings generally develop because the glass fails, this occurs most frequently because the supporting structures, the roof pillars and related components, fail. Even without laminated side glass, greenhouse integrity in rollovers would tend to minimize glass breakage and thus ejections –complete and partial- regardless of whether or not the belt is used. This consideration is probably more important than the "direct cause" theory of injury related to roof crush. If we accept the view that in general, ejection should be prevented, it makes this first question irrelevant.

Structural Failure and Injury Causation in Rollover Accidents

Theories positing the irrelevance of roof crush then, are subject to at least the following criticisms: The vehicles and rollovers in the evidentiary tests involve dimensions and kinematics that maybe unique, unrepresentative and misleading; the occupant kinematics are thus similarly problematic. The injury mechanics and related claims are dubious because of the problems with the kinematics and because of biofidelity problems with Hybrid III dummies in the subject accident modality. The theorists ignore the evidence from heavy vehicle accidents and from the designs of various European manufacturers. The statistical analysis is irrelevant because the good vehicles are not sorted out for comparison with the bad and because the analysis is based on a dubious assumption, namely that the amount of roof crush is theoretically relevant. The theory in total is irrelevant from the standpoint of design and regulation because greenhouse integrity would minimize ejections regardless of the question of direct injury etiology. An additional consideration, presented here without full argument or justification, is that it is obviously false according to long accepted principles of vehicle crashworthiness. Structural integrity of the vehicle is always relevant in crashworthiness analysis, the severity of the second collision is in part determined by it. Those who claim otherwise face an onerous burden of proof, one thus far not met.

The theory that structural integrity is irrelevant in rollovers has been largely spared the experimental data that might raise serious doubts about it until fairly recently. But a new article has cast some light on the question. Habberstad et. all. reported (reference 6.) that accelerometer reading in excess of 100 g's were recorded on the roof header in a Ford van rollover test. The recorded values ranged from 14 g's to 111g's on the roof header in the vicinity of the "C" pillar. We cannot be sure that these are maximum values or even generally representative values for all rollovers onto hard surfaces, nor even that all rollovers produce high local forces if the roofs collapse. However they are suggestive of an important general consideration concerning structural failures in highway vehicles under impact conditions. Something we in fact have known for a long time. *High local forces generally develop when the structures fail*.

The author is currently reviewing barrier crash tests for a small pickup. Peak loads experienced by some components are in excess of 200 g's in some tests. The overall center of mass deceleration is about 30 g's for these tests, but the local forces associated with failing components are many times higher. The center of mass deceleration is, of course, an average value associated with the entire process, the force experienced by undamaged parts of the vehicle. The comparable value for rollovers is about 10g's, but much higher local forces will be produced when individual components fail. Anything coming in contact with elements of the vehicle experiencing these high levels of acceleration will itself be subject to high accelerations and the associated forces. This is analogous to the second collision in an ordinary planar accident when the occupants strike the passenger compartment while it is collapsing in on them. The contact velocities are not due to the occupant velocity alone, but rather are a function of both the occupant's velocity relative to the undamaged parts of the vehicle and the velocities of the collapsing vehicle components.

What happens to a human neck when the moving head is hit by a piece of the greenhouse that is experiencing a level of acceleration of 100g's or greater? From elementary kinematics we know that accelerations, as vectors, combine just as velocities do. There will be a deceleration of the head due to the impact, the same as there would be if the surface being struck was not itself experiencing a rapid acceleration; this will then combine with the acceleration of the collapsing vehicle component to result in a higher impact force than would be generated by the contact without the moving strike surface. If the duration of the force and resulting displacement along the line of action are great enough there may be serious injuries. Indeed, these two parameters might be more important than the maximum force level once a critical minimum value is reached. Forces must have a duration in time to effect momentum transfer, and act through a distance to do work. Mechanical effects on any system are dependent on these time and distance variables.

This notion of combining accelerations is easy to understand with the following thought experiment. Imagine that you are about to be struck by an "A" pillar being rapidly swung at you with an appreciable mass behind it. Would you rather be moving toward the "A" pillar or away from it? Clearly if you are about to be batted in the head, you want to be moving away from the bat when it gets to you. (You would also want the bat padded for the sake of your head, if not your neck.) Imagine also the problem of trying to bunt a baseball while moving the bat away from the pitch, contrast that with the low forward velocity normally associated with bunting or with swinging for the seats. These complication: Proximity to the collapsing structure at the right time, velocity relative to the collapsing components, orientation of the head and neck, all help explain why serious head and neck injuries don't always occur in rollover accidents. Being in a rolling vehicle with a collapsing roof is analogous to being shot at. If your shot at you may not be hit, and even if your hit the outcome depends on where and how you're hit. But just as it is advisable to get shot at, it is impermissible that vehicle roofs collapse in rollover accidents.

What apparently happened in the Malibu tests is that the dummies simply did not experience the type of severe impacts sometimes encountered by humans in actual rollover accidents. Data from the tests shows no high accelerations as appeared in the Habberstad study. The accelerometers were located on the "B" pillars at the c.g. height. That is, relatively low and out of harms way. The highest acceleration recorded was on the order of 60 m/sec/sec, about 6 g's. And the published results never show high dummy forces concurrent with high vehicle forces. In reference 1.The authors make the following comment: "Most of the dummy impacts in this study occurred when the head of the dummy remained in contact with a portion of the vehicle" (generally the roof rail) "as the vehicle impacted the ground…" (Others involved the dummies moving across the vehicle and hitting something.) In other words, the dummy is already in contact with a portion of the vehicle which was, evidently, not even decelerating rapidly when the supposedly significant events, the ground contacts, occurred. The situation was somewhat analogous to a case of "ridedown" in a planar accident that does not involve exposure to high g loads associated with a collapsing structure. The dummies were lucky, in that like most people involved in rollovers they did not experience the most harmful events- impacts with vehicle structures collapsing under high g's. Perhaps, also, these tests failed to produce the high levels of vehicle component accelerations that occur in other types of rollovers.

CONCLUSIONS:

For non-ejected occupants, greenhouse collapse is generally a necessary but not sufficient condition for serious head and neck injuries in rollover accidents. Greenhouse failure in rollovers thus marks a defective condition for those vehicles that exhibit it. Even if greenhouse failure did not produce injuries, in and of itself, it contributes to ejections which expose the occupants to additional injury risks.

REFERENCES

1.*Rollover Crash Tests-The Influence of Roof Strength on Injury Mechanisms*, Kenneth F. Orlowski, R. Thomas Bundorf, Edward a. Moffatt, SAE 851734.

2. *Rollover and Interior Kinematics Test Procedures Revisited*, John L. Habberstad, Roger C. Wagner, Terry M. Thomas, SAE 861875

3*. An Evaluation of Door Locks and Roof Crush Resistance of Passenger Cars*, Charles J. Kahane, DOT HS 807 489, November, 1989.

4. *Rollover and Drop tests-the Influence of Roof Strength on injury Mechanisms Using Belted Dummies*, G. S. Bahling, R.T. Bundorf, E.A. Moffatt, K.F. Orlowski, J.E. Stocke, SAE 902314

5*. Occupant To Roof Contact: Rollovers and Drop Tests*, Stephen R. Syson, SAE 950654

6*. A Comparison of the Controlled Rollover Impact system (CRIS) with the J2114 Rollover Dolly,* Jarrod W. Carter, John L. Habberstad, Jeffrey Croteau, *,* SAE 2002-01-0694*.*
.
7. *Crashworthiness of Large Poststandard Schoolbuses*, NTSB/SS-87/01

8*. Improved Vehicle Design for the Prevention of Severe Head and Neck Injuries to Restrained Occupants in Rollover Accidents*, Keith Friedman, Donald Friedman, "United States Paper Number 96-S5-0-14"

9. *Examination of Rollover Accident Characteristics, Using Field Data Performance,* Jeya Padmanaban, Martin Stone Davis, SAE 2002-01-2056

APPENDIX

CHILDREN'S HOSPITAL BY SQUADS

	INJURIES	DISPOSITION
KEPLAR, Jennifer	COLLAR BONE	TREATED/RELEASED
JACKSON, Kim	HIP PAIN	TREATED/RELEASED
HOLLAND, Ashley	SHOULDER	TREATED/RELEASED
GREEN, Jennifer	HEAD & SHOULDER	TREATED/RELEASED
FLEMING, Thomas	PAIN HEAD/BACK/NECK	TREATED/RELEASED
JARRETT, Jessica	ABDOMEN/SHOULDER	TREATED/RELEASED
LEATHERWOOD, Claire	HEAD/LACERATIONS	TREATED/RELEASED
KASLER, David	HEAD/LACERATION	TREATED/RELEASED
PRESTON, Richard	SHOULDER/NECK	TREATED/RELEASED
HARNESS, Stephanie	LACERATION/BELLY, LEFT & RIGHT HAND	TREATED/RELEASED
MILLER, Amy	HEAD PAIN	TREATED/RELEASED
NUNGESTER, Tasha	NECK & BACK	TREATED/RELEASED
HELTON, Cody	LACERATION/R SHOULDER	TREATED/RELEASED

BERGER HOSPITAL (BY SQUADS)

HECKLER, Adam	LUMBAR STRAIN	TREATED/RELEASED
IRWIN, Ashley (Ally)	NECK STRAIN	TREATED/RELEASED
HAVENS, Brad	FLANK PAIN	ADMITTED #3 FLOOR OBSERVATION
NOLAND, Payton	LUMBAR STRAIN	TREATED/RELEASED
LANNING, Marsha A.	LOW BACK STRAIN	TREATED/RELEASED
PETERS, Aaryn	R-HAND LACERATION	TREATED/RELEASED
HENSON, Cassidy	R-HAND & SHIN ABRASIONS	TREATED/RELEASED
HOOVER, BEVERLY (Bus Driver) (BY PRIVATE VEHICLE)	HEMATOME	TREATED/RELEASED

BERGER HOSPITAL (BY SCHOOL BUS)

HORNBERGER, Kelsey	MULTIPLE LACERATIONS	TREATED/RELEASED
GOODKNIGHT, Thomas	FINGER LACERATION	TREATED/RELEASED
KISER, Chris	ARM & CHEST ABRASIONS	TREATED/RELEASED
HELTON, Meagan	CHEEK CONTUSIONS	TREATED/RELEASED
HELSER, Adrian	MULTIPLE ABRASIONS	TREATED/RELEASED
HUNT, John C.	MINOR ABRASIONS	TREATED/RELEASED
JONES, Troy	MUSCLE INJURY	TREATED/RELEASED
OGLES, Elliot	MAXILLA CONTUSION	TREATED/RELEASED
PORTER, Reese	**NO INJURY**	
HASTINGS, Derek	LACERATION R-MIDDLE FINGER	TREATED/RELEASED
KEITH, Nathan	**NO INJURY**	
HARRIS, Joshua	ELBOW & NOSE ABRASIONS	TREATED/RELEASED
NUNANAKER, Billie J.	R-ELBOW STRAIN	TREATED/RELEASED
GREGG, Zane	ABRASIONS	TREATED/RELEASED
KIRK, James	R-WRIST CONTUSIONS	TREATED/RELEASED
FINK, Jonathan	FACIAL CONTUSIONS	TREATED/RELEASED
PHELPS, Thomas	**NO INJURY**	
TUSSING, Ronnie (ASSISTING IN RESCUE)	SMOKE INHALATION	TREATED/RELEASED

GRANT HOSPITAL

KARSHNER, Karen (Adult) Hamilton Twp. Medic	NECK, BACK & HEAD	TREATED/RELEASED