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# AN ALTERNATIVE ANALYSIS OF ROLLOVER HEAD AND NECK INJURY DATA

by

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*This paper was presented at the 19th Annual Workshop on Human Subjects for Biomechanical Research. It has not been screened for accuracy nor refereed by any body of scientific peers and should not be referenced in the open literature.*

Good Afternoon, Mr. Chairman, Ladies and Gentlemen:

As shown here, head and neck impacts in automotive accidents are a big problem, and result in a large number of severe injuries and fatalities annually.

| ANNUAL U.S. HEAD AND NECK INJURY STATISTICS |
|---|
| * 27% of all HARM involves the Head and Neck (H & N) |
| * 41% of H & N HARM comes from Roof and Supports |
| * 7400 Severe and Critical Head Injuries |
| * 5900 Fatal Cervical Spine Injuries |
| * 3100 Severe Spinal Cord Injuries |
| * 500 Quadriplegic Injuries |

**My impression is that little or nothing is being done to limit the number and severity of such injuries in side impacts and rollovers.**

Therefore, the two purposes of this paper are to:

define the factors on which Head and Neck Injury Risk depends;

and to identify safety features which could reduce the frequency and severity of such injuries particularly in rollover accidents.

Those safety features should reduce the risk of severe injuries and fatalities by a factor of at least four. In the U.S., those features could save annually as many as 5000 lives and 5000 severe and critical head and neck injuries.

And the estimated cost is less than 50 pounds of weight and $250.

First, I'd like to describe the four studies on which this paper is based.

| STUDIES TO QUANTIFY PROBLEMS AND SOLUTIONS |
|---|
| 1. STATISTICAL ANALYSIS OF ROOF CRUSH CASUALTIES<br>2. FIFTEEN IN-DEPTH ROLLOVER ACCIDENT INVESTIGATIONS<br>3. DEVELOPMENT OF HEAD/NECK INJURY COUNTERMEASURES<br>4. SIXTEEN ROLLOVER TESTS WITH HYBRID III DUMMIES |

The first was a statistical analysis of 1982 and 1983 National Accident Sampling System rollovers. It showed that people who were seated under a badly crushed roof area were 4 times more likely to be severely injured than people who weren't.

The second was the detailed investigation of 15 rollover accidents using computer simulations to analyze the trajectory and roll, the occupant kinematics and the injuries.

The third was to develop countermeasures based on critical biomechanical injury measures and assess their effectiveness.

The fourth was a detailed analysis of the instrumentation and photographic data from sixteen nearly identical, rollover tests conducted by General Motors. Those tests mixed production and rollcaged roofs, and unrestrained and belted Hybrid III dummies.

The following material was selected from the more detailed 13th International ESV Conference paper in Paris # 91-S6-0-11, "Roof Collapse and the Risk of Severe Head and Neck Injury" to highlight some of the studies, what was done and what we found particularly interesting.

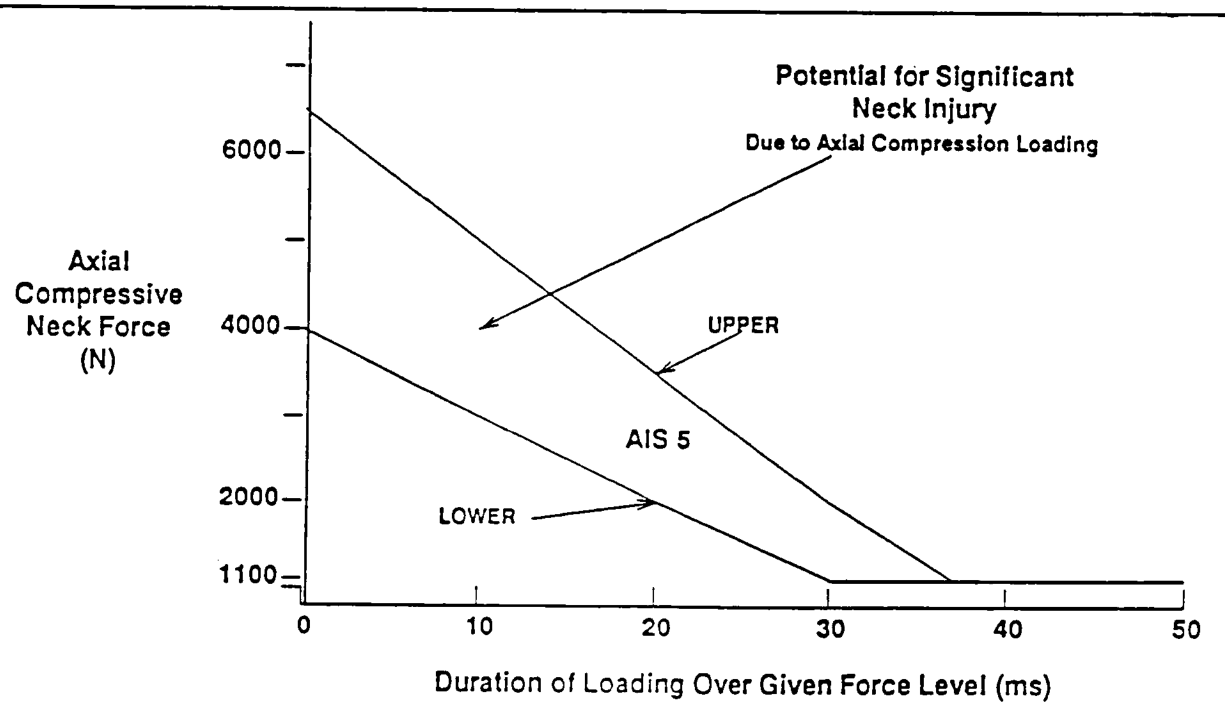
This chart summarizes and shows the scope of the 15 reported case investigations. It includes 1975 to 1988 vehicles from a Pinto to a Buick LeSabre, and from a Nissan 280 Z to a full size pick-up truck. Each case is listed by the extent of Roof deformation; the number, type and level of injury under the deformed roof; other people in the same car and their approximate level of injury. The last column indicates the least costly, effective countermeasure analyzed.

## ROLLOVER ACCIDENT CASE FILE SUMMARIES

| Case Vehicle | Roof Deform Extent | Injured by roof # / AIS | Other Injured # / AIS | Effective Countermeasure |
|---|---|---|---|---|
| 1. 1975 Pinto | = 5 | 1 / 5 | 1 / < 2 | Structure |
| 2. 1983 Blazer | > 3 | 1 / 6 | 2 / < 2 | Strt & Pad. |
| 3. 1986 Escort | = 5 | 2 / 5 | 1 / < 2 | Strt & Pad. |
| 4. 1981 LeSabre | > 3 | 1 / 5 | 3 / < 2 | Strt or Pad. |
| 5. 1984 Toy P/U | > 4 | 1 / 4 | 1 / < 2 | Strt or Pad. |
| 6. 1980 280 Z | > 2 | 1 / 4 | 0 | Strt or Pad. |
| 7. 1976 Dodge | = 5 | 2 / 5 | 1 / < 2 | Strt & Pad. |
| 8. 1983 Camaro | = 5 | 1 / 5 | 0 | Structure |
| 9. 1981 F150 P/U | > 2 | 1 / 5 | 4 / < 3 | Padding |
| 10. 1988 2500 P/U | = 5 | 1 / 5 | 0 | Structure |
| 11. 1985 Bronco | = 4 | 1 / 5 | 1 / < 3 | Structure |
| 12. 1988 BMW | = 1 | 2 / 6 | 5 / > 1 | Padding |
| 13. 1981 Subaru | = 1 | 1 / 5 | 1 / 1 | Padding |
| 14. 1988 Samarai | = 0 | 1 / 5 | 0 | Padding |
| 15. 1976 260 Z | = 3 | 1 / 5 | 0 | Padding |

Computer simulations were used to characterize the vehicle trajectory and roll, the occupant kinematics, the injuries and the relative effectiveness of various countermeasures.

## HYBRID III DUMMY AXIAL NECK COMPRESSION INJURY MEASURES



Those computer simulations used a GM Hybrid III dummy. GM defined 4000 newtons as the dummy axial compression neck loading likely to produce significant injury. Others suggest that critical AIS=5 quadriplegic injury is likely in a range between 4000 and 6500 newtons.

A specific case example of the relative effectiveness of two countermeasures is shown on this figure.

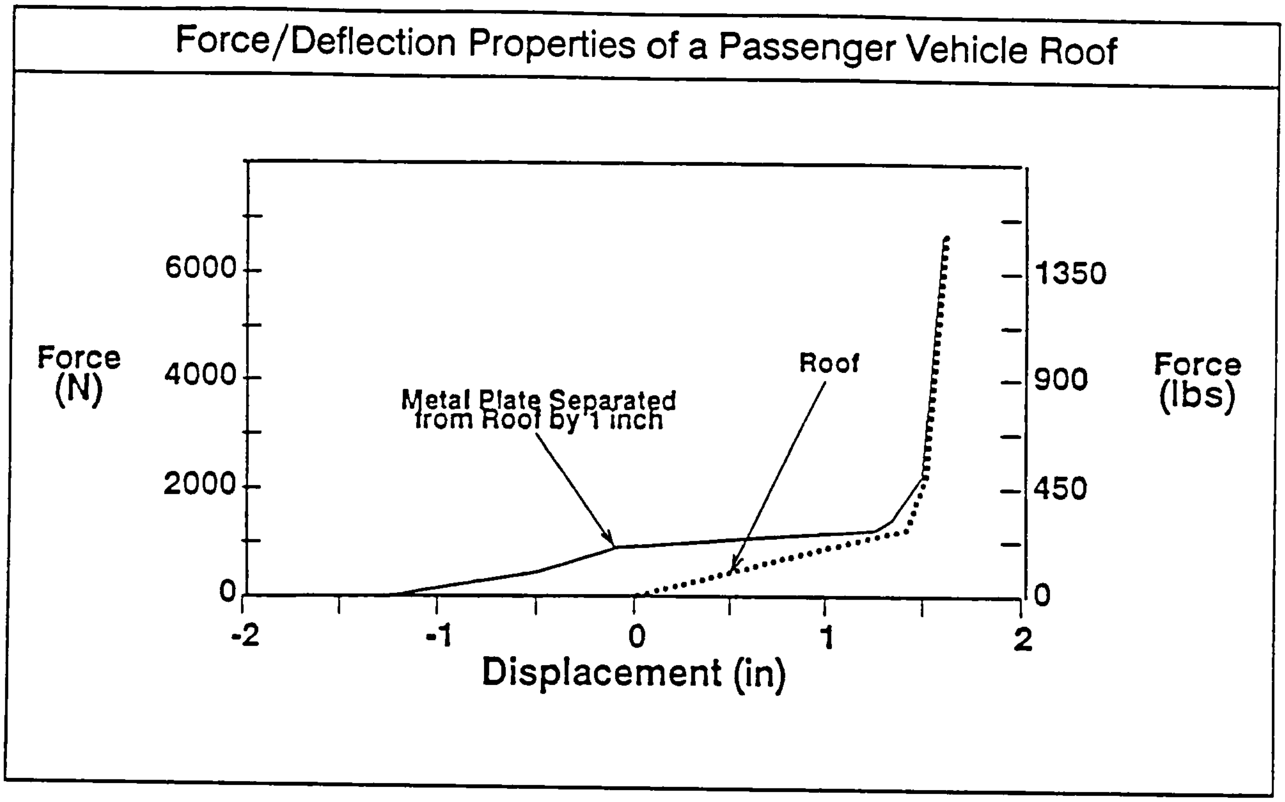
RESULTING INJURY MEASURES FROM CASE ALTERNATIVES

| **Parameter** | **Actual** | **Stiffer Roof** | **Stiffer Roof & belt tension** |
|---|---|---|---|
| Crush over victim | 30cm | 15cm | 15cm |
| Belt Slack (each) | 1.75" | 1.75" | 0" |
| Belt Loads (newtons) | 405 | 1303 | 2607 |
| Torso Belt load | 0 | 0 | 1095 n |
| Lap Belt load | 405 n | 1303 n | 2607 n |
| HIC | 343 | 67 | 26 |
| Neck Shear Forces | -95 n | 178 n | 245 n |
| Neck Moment | 2 nm | 1.5 nm | -37 nm |
| Neck Rel. Compressive Time | 55 ms | 90 ms | 100 ms |
| **Peak Neck Compressive Force** | **4727** | **2309** | **1061** |

The first column represents the accident circumstances and the quadriplegic injury experienced at 4727 newtons, the second the effect of a stiffer roof at 2309 newtons, and the third, the effect of a stiffer roof and emergency tensioned belts removing available slack at 1061.

The padding countermeasure was investigated by measuring the static force/deflection properties of production vehicle roofs with a head form. A 22 gauge plate with 1" high tabs on 6" centers was then inserted between the headform and the roof and the measurements repeated.

The results below show that the metal padded roof limits the force to less than 2500 newtons while absorbing twice the energy of the conventional roof. Translated to neck compression injury measures, it means that one inch of metal padding on the inside of a roof can probably limit neck forces to below 2500 newtons, at head contact velocities below 3.0 meters/second, when the production roof would produce 8000 newtons.




Considering current automotive styling trends, an alternate countermeasure approach is the monocoque rounded roof structure of the Minicars Research Safety Vehicle which rolled three times without excessive far side roof rail acceleration or deformation. It provided 4 inches of roof deformation without intruding on the occupant's survival space. The angled interior roof contact surface was designed to flex the head and neck to preclude axial loading.

The following chart summarizes the unejected, interior contacts on the driver's head and neck, in 16 General Motors rollover tests.

The number of contacts is listed, each of which exceed suggested injury measures, as well as the maximum force in each catagory.

In the first series of 8 tests, the dummies were unrestrained, while in the second set of 8, the dummies were slackly belted to represent how human occupants wear belts. Half the vehicles in each series included an unpadded 160# roll cage, so only production roofs collapsed.

In the unrestrained tests, where driver dummies were often out of place, there are eight production and 5 rollcaged driver contacts at more than 4000 newtons, but for over 5000 newtons with shear, the numbers are 2 and 0 respectively.

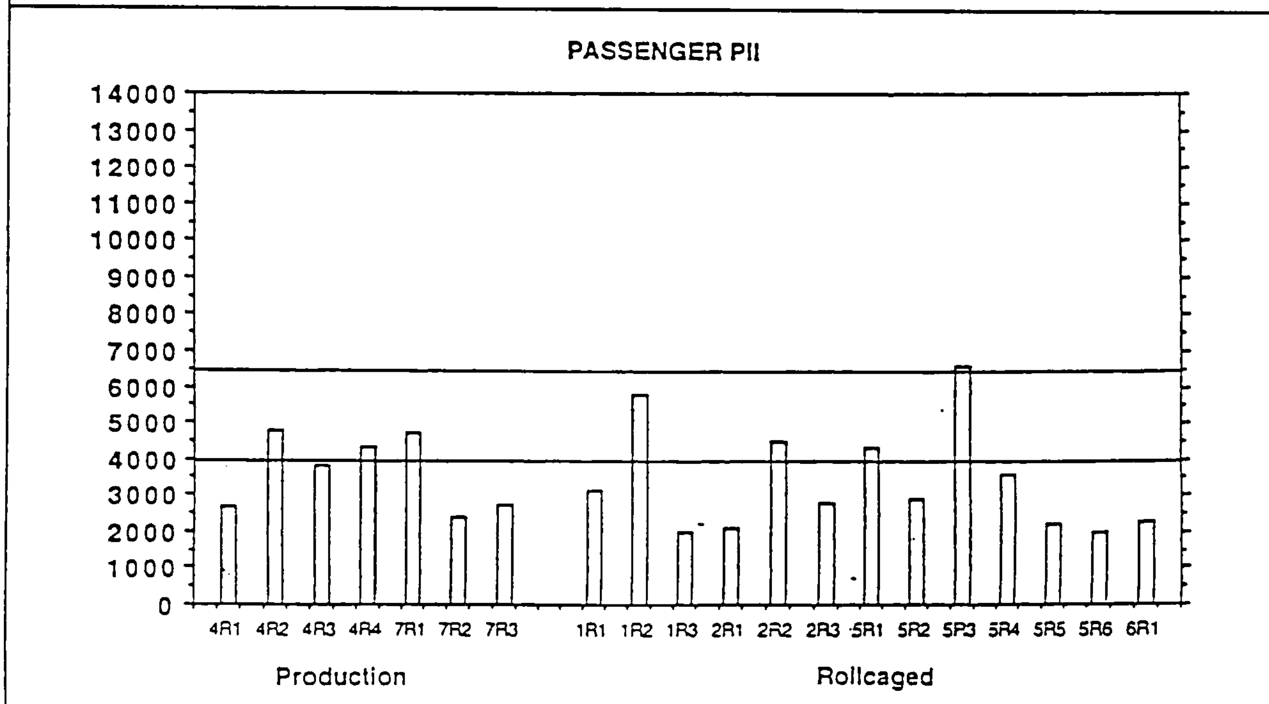
In the belted tests, where the driver dummy was held under the collapsing roof, the ratio of the number of production and rollcaged contacts was 11 to 2 and 5 to 0 for the relevant injury measures.

**Unejected, DRIVER Head/Neck Measures in 16 GM Rollover Tests**

| TEST CONDITION (4 each) | AXIAL NECK MEASURES PII >2kn | Std >4kn | Max kn | >5kn+1kn shear | NECK MOMENTS flex >190nm lat, ext > 57nm | HIC = or > 1200 |
|---|---|---|---|---|---|---|
| UNRESTRAINED | | | | | | |
| Production | 13 | 8 | 7.8 | 2 | 4 | 1 |
| Rollcaged | 11 | 5 | 5.7 | 0 | 2 | 1 |
| BELTED | | | | | | |
| Production | 15 | 11 | 13.2 | 5 | 10 | 0 |
| Rollcaged | 4 | 2 | 5.6 | 0 | 1 | 0 |

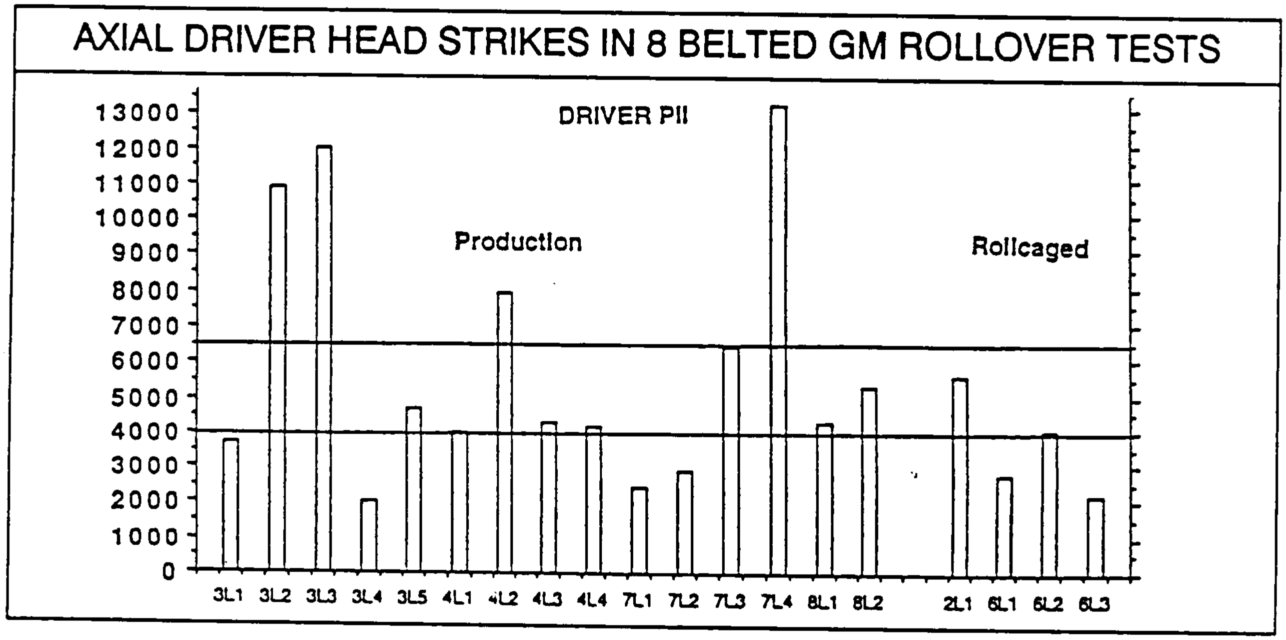
This chart shows some detail of the passenger axial compression loadings during the belted tests on a scaled background of the injury measures.

**AXIAL HEAD STRIKES IN 8 BELTED GM ROLLOVER TESTS**

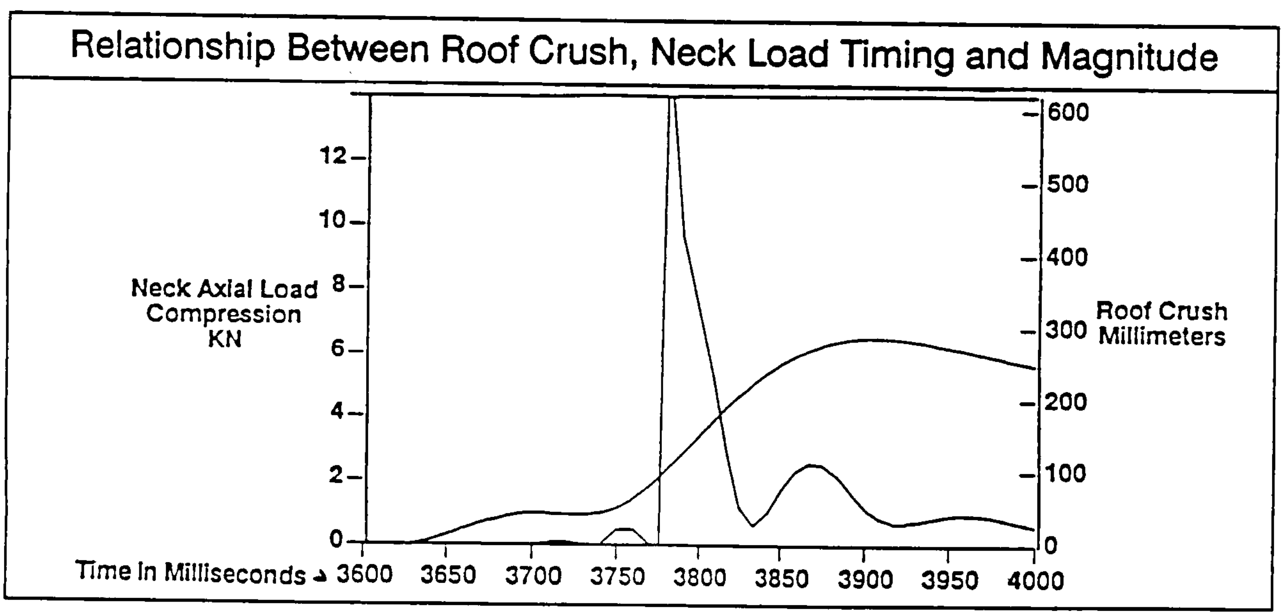


Notice that there are a ratio of 3 production to 4 rollcaged loadings over 4000 newtons, but remember that one inch of the metal roof padding described earlier will reduce 8000 newton loads to 2500 newton loads, so that all axial compression injuries would be eliminated.

These are the belted driver impacts. Notice again the 5 to 1 frequency of axial compression loadings over 4000 n between production and rollcaged cars. And, each strike above 6500 newtons occurred during significant roof crush.




This is an estimate of the true relationship between roof crush and the maximum axial neck compression loading in 7L4. As you can see, roof crush preceeds the neck load and contributes to the contact velocity.



These results corroborate the findings of the field case analyses and directly contradict GM's contention that - and I quote - ..."rollcaged vehicles did not have any increased level of protection over the standard roof vehicles in these tests".

In conclusion, we found that:

The risk of critical head/neck injury is dependent on:

roof interior head/neck clearance; the roof's shape; the extent, greater than 3, of roof deformation; the interior surface's force/deflection characteristics; and the occupant's belt slack.

These studies demonstrate that:

eliminating roof collapse is a key factor in limiting head and neck injuries, and is even more important with belted occupants. Furthermore, passive interior padding should be added to the roof and upper support structure, and belt slack should be eliminated by emergency tensioning retractors.

Some other conclusions of interest are:

The Case study analyses show that in rollovers, the magnitude of head/neck forces is related to the orientation of the head, neck and torso and the closing velocity of the head and roof structure at contact.

GM photographic data and timing indicates that contact generally occurred some 25 to one hundred milliseconds earlier than the axial neck load confirming the relationship between velocity and extent of deformation.

Statistical data analysis shows a factor of four greater risk of critical injury when an occupant is in the proximity of roof crush with deformation extent index greater than 3. Case studies and GM test data confirm this.

GM test data indicates that restrained occupants are at significantly increased risk of head and neck injury from roof collapse than unrestrained occupants.

A stronger roof, which does not collapse, may change the dynamics of the rollover, so that far side roof rail contact is less likely and less severe.

One production car roof in each GM series of tests, did not collapse, indicating that light weight structural modifications would suffice.

## DISCUSSION

PAPER: **An Alternate Analysis of Roll-Over Head and Neck Injury Data**

SPEAKER: Don Friedman, Liability Research

QUESTION: Rolf Eppinger, NHTSA

I'm confused about this metal liner with the posts and how when you tested it, it gave you the force. Were you testing that without anything on the roof itself - you were just pushing up into it. And then you added this inter-liner with little standoff posts and it generally produced more load, if I look at your force deflection curve than the roof itself, so it made it stiffer. I was trying to understand you said that because of that, during the rollover you were getting some benefit from it.

A: It made it stiffer initially but it basically provided a force limiting effect.

Q: If I now fall on this thing that has this small amount of force limiting affect in it, at 1000 Newtons for a couple inches...

A: It's not a question of falling on it, it's a question having a similar contact velocity. We already have an accident so we already know what's happened and we hit a roof and generate a certain injury. That was the example that I used. If you use up one inch of space if you make the roof one inch higher so that you now have a sort of composite roof with a metalized liner, which is separated from the main roof by one inch, what happens to the head is that it follows the force displacement properties of the solid line that you see there. And the result of that is a reduction in the neck compression loading while the energy is being used up from the contact velocity and it doesn't matter whether the roof is coming down on the occupant or the occupant is going up into the roof, given the orientation of the occupant...

Q: How much velocity benefit do you claim comes from that?

A: What we find is that one inch equals about 3.3 meters per sec.

Q: I can't recall the GM films of the rollover when head contact occurs.

A: I can and I've been trying to get GM to provide that data, they have provided only a limited amount of that information, but my analysis is that it's somewhere between .8 to 3.3 meters per sec. is what is occurring in the contact between the occupant and the roof when the roof crush doesn't occur.

Q: But that's generally when he's upside-down, the roof is close to or on the ground and he's falling towards the roof, and either it crushes or he stops and falls on it. But it's not in the opposite direction, he's not propelled into the roof, vertically up; it's when the car is inverted.

A: Let's stay with the GM tests. In the GM tests, they provided me with the data for each of the impacts that resulted in an axial neck compression of greater than 2000 newtons. So I can analyze only those and the amount of the data they provided for the photographic was limited. In fact they provided data for less than a quarter of the number that were involved. In the ones that they provided, the contact velocity was in the range of less than 3.3 meters per sec. We have also considered the same situation from the point of view, suppose the roof comes down and the occupant is not moving, because in the real world data what we find that lots of times the occupant is moving into the roof only partially restrained by the belt assembly and sometimes the roof is coming down and hitting him when he's in the seat or off the seat. So we've considered both of those and what you find is that it takes quite a bit of roof crush to produce a velocity increase which is like 50% more than the velocity the occupant has when going up into the roof. So anything more than about 5 meters per sec. is where you're getting these very high spikes that you saw in the 10,000 - 13,000 Newtons. Those are occurring when the roof velocity is being added to the occupant velocity moving towards the roof.

Q: I'm confused because of the inertial reference frame. If a car is upside-down and has a roll cage but the roof is making contact with the ground it necessarily has a 0 velocity.

A: No that's wrong - that was a big point in the Paris discussion with Murray MacKay. There is a tendency to think of a roof crash as being a vertical effect, a vertical phenomena. It actually is a function of another factor which is the vector velocity. And the vector velocity is almost always strongly influenced by the lateral velocity of the vehicle as compared to the vertical. When a vehicle's rolling, it's rolling at about 4 times the lateral velocity than it is the vertical velocity at contact. And so it's very easy for the contact velocity, the resulting velocity at the point of contact, to be a couple of meters per second higher than the vertical velocity.

Q: But how can the lateral velocity hurt me? Let's keep the velocities in the inertial frame--vertical or horizontal. If my roof is at zero velocity in a vertical direction if I fall on it with my head, I will have a certain impact. If I put padding, possibly the padding can attenuate some of that load. If I put a roll cage on that or have the roof not crushing, the roof velocity in a vertical direction is still zero. So, what benefit does the roof crush, or preventing the roof crush, have in attenuating the velocity of the roof while it's in contact with the road, because it's zero in both cases.

A: Yes, I hear what you're saying but I'm telling you that when you have a rollcage in the GM tests themselves, you don't get a head loading or neck loading which exceeds about 6000 Newtons. And so the question is, how come you get higher than those kinds of loadings when you have roof crush? And the answer is that it's not just the vertical velocity that's producing the roof crush it is the composite velocity that is producing a difference in the contact velocity between the body augmentation, or however you want to think of why the person is moving towards the roof and how the roof is moving towards the occupant. This vehicle is rolling, it never falls flat.

Q: Does he get trapped during this roof crush, I mean does the seat then come down and push on his body and push him further down into this...

A: Not in the GM tests. I do have a single case in a pick-up truck where that's the case, yes. But not in the GM rollovers.

Q: So the reason that the velocity of impact is attenuated is because the roof is further away from him? When the car goes over and makes contact with the road, the inertial velocity of the roof in a vertical direction is zero. If I come down and hit that, I look at the human body in inertial space, he's hitting a surface that's at zero velocity and he has some velocity toward it.

A: Yes, but this is a transient rolling effect. The area of the roof that is in contact with the head may not necessarily be the area of contact between the roof and the surface [of the road]. There's a difference and as soon as you assume that the contact area on the head to the roof is the same as the roof to the road, you draw the conclusion that there you're drawing, i.e. there can be no increase in velocity. But the facts in the GM study, the reason why they got higher neck loadings when the roof is collapsing, the reason that you saw that slide where General Motors wanted to say that the roof crush doesn't occur until after the axial neck loading is a crucial point. It doesn't occur after the neck loading, the maximum occurs after the neck loading; the roof crush doesn't occur until after neck loading occurs. That, in fact, from their data is, as far as I'm concerned to the degree that I can discuss it here, is not correct or at least it is in question.

Q: Carly Ward, Biodynamics

In your earlier slide you had grades of roof crush and I'd like to know what those grades were where you gave them numerical values and what those grades represent.

A: That's the CDC level a deformation of 5 is down to the window sill, 3 is about six inches.

Q: Were you finding injuries related to those numbers? Were you able to correlate your injury patterns with those numbers?

A: Not really. What I was able to do, when you had very deep roof crush you could when you set up the model to model what really happened and you put the crush in, you see why you get very high loads and if you then postulate a counter measure, which is a stronger roof, what you see is that the effect is significantly reduced. Maybe not reduced enough unless you get the roof crush to less than about six inches, depending on roof height.