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March 25, 2008

The Honorable Nicole Nason
National Highway Traffic Safety Administrator
Washington, D.C. 20590

Summary Comments for Federal Motor Vehicle Safety Standard (FMVSS) 216, Roof Crush Resistance Docket No. NHTSA-2008-0015 (49 CFR Part 571.216)

Dear Ms. Nason,

Technical data from the National Highway Traffic Safety Administration (NHTSA); recent research by the Insurance Institute for Highway Safety (IIHS) and the Center for Auto Safety (CAS); information presented at our briefings of November 5 and December 9, 2007; test results in our February 25, 2008, submission to the docket; and data in the appendix to this submission lead to an inescapable conclusion:

> The minimum regulatory requirement, necessary to significantly reduce the risk of injury to restrained and unrestrained occupants whether ejected or not, is a two-sided quasi-static test (or equivalent) in which the first side is tested at 5° pitch and 25° roll with a minimum strength-to-weight ratio (SWR) criteria of at least 3.5, and the second side is sequentially tested at 10° pitch and 40° roll with a minimum SWR criteria of at least 2.0, both through a full 5 inches of platen displacement, at maximum unloaded vehicle weight.

A summary of the technical basis for that conclusion is as follows:

- NHTSA's research,[1,2,3] based on National Accident Sampling System (NASS) cases, indicates that direct contact injury is five times more likely at all injury levels in rollovers where the residual post crash headroom is negative.[4,5]
- Based on NHTSA's criteria, the Jordan Rollover System (JRS) dynamic tests of recent and current production automobiles and SUVs found that a minimum strength-to-weight ratio (SWR) of 3.5 was required to ensure that the residual post crash headroom is positive in most typical flat ground rollovers.[6]
- IIHS's statistical analysis of actual rollover crashes indicates a 28% decrease in injury potential for each unit increase in SWR criteria in the FMVSS 216 test.[7]

- JRS dynamic tests indicate a 24% decrease in roof crush injury potential for each unit increase in FMVSS 216 SWR, which correlates with the IIHS conclusions, although our tests covered a wider range of vehicles and model years.
- Experimental Malibu and JRS dynamic tests demonstrate the difference in ejection potential based on roof strength. In 21 JRS single roll tests, 13 of the tested vehicles with an SWR less than 3.5 had fourteen front side tempered glass windows broken in the test; while eight of the vehicles with an SWR greater than 3.5 had only two broken side windows. This suggests a fourfold reduction in front seat ejection potential. Thirteen rear side windows broke and two doors opened in the low SWR group, while no rear side windows broke in the higher SWR group. This, and similar results in the Malibu tests, suggest a substantial reduction in front and rear seat ejection potential.[8]
- JRS dynamic tests indicate roof crush intrusion speed,[9] not diving,[10] is the cause of serious to fatal head or neck injury. This data contradicts the submission of Safety Analysis Inc.[11] JRS crush speed data show a 21% decrease in injury potential for each unit increase in FMVSS 216 SWR.
- IIHS fatal and incapacitating injury rate data versus SWR, correlates well with the slope of JRS dynamic test results using 50th % Hybrid III dummies and NHTSA's probability of injury functions (based on Nij for AIS 3+ and AIS 5+ injuries).[12]
- JRS tests of a 2007 Toyota Camry, a Hyundai Sonata and a Chrysler 300, sponsored by the Santos Family Foundation through the Center for Auto Safety confirm these relationships.[13]
- The Malibu dolly rollover dynamic tests indicate that of 27 Potentially Injurious Impacts (Piis) there were no injurious head strikes to unrestrained, non-ejected front seat occupants of vehicles with roll cages, while there were 3 injurious impacts among 26 Piis in the production Malibus.[14]
- A minimum SWR greater than 3.5 in the one sided FMVSS 216 test is not sufficient to protect occupants. NHTSA's sequential second side testing at 5 x 25 had an average loss of strength of 8%. However, in our extensive testing in the M216 fixture at 10° pitch and 40° roll the average crush resistance is 50% lower than the crush resistance in the FMVSS 216 test, often as a result of header buckling from the greater longitudinal and lateral loading. These loading conditions are characteristic of serious to fatal NASS investigated rollovers.[15]
- Some current model vehicles with 4 or 5 star side impact ratings have FMVSS 216 SWR greater than 4 with no new regulatory requirement. However, an analysis of all NASS cases involving 2003 and later Toyotas (most of which have FMVSS 216 SWR greater than 4) involved in uncomplicated rollovers showed that about half had buckling of the weak windshield header, some of which resulted in significant head or neck injury . This was reported in a CAS submission[16,17] and is summarized in appendix D.

- The appropriate target population for this regulation should be the 18,029 serious to critical injuries and 6,712 fatalities, reduced by the benefits estimated from the electronic stability control standard. At the same time, and consistent with the Office of Management and Budget guidelines, only the added cost of longitudinal and lateral increased roof crush resistance should be assigned to this standard.[18]
- As demonstrated in this submission, dynamic rollover tests can be used to identify quasi-static roof strength criteria and validate statistical analyses of real world crashes. However, we continue to believe that dynamic tests are the best and only means of assuring rollover occupant protection and accurately informing consumers of a vehicles relative performance quality.

It would be unconscionable to deny or ignore NHTSA's own data and analyses, and the information submitted by other reputable, independent researchers in the establishment of an effective roof crush standard. Should further clarification or data be required from us, we would be pleased to meet with you to answer questions and to add data from our continuing research and testing. We are strongly motivated to cooperate in this important work on behalf of the 25,000 people who are seriously to fatally injured in light vehicle rollovers annually.

Respectfully Submitted,

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Appendix

A. Roof Crush Speed and Injury Potential vs SWR,
B. Correlation of Statistical and Experimental Injury rate, Injury probability and injury potential,
C. Diving Data Analysis,
D. Ejection and Unrestrained Injury Potential,
E. Structural and Cost Analysis,
F. Miscellaneous Comments and Corrections.

References

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[1] Rains, G., Kanianthra, J., "Determination of the Significance of Roof Crush on Head and Neck Injury to Passenger Vehicle Occupants in Rollover Crashes," SAE 950655

[2] Austin, R., Hicks, M., Summers, S., "The Role of Post-Crash Headroom in Predicting Roof Contact Injuries to the Head, Neck, or Face During FMVSS No. 216 Rollovers," NHTSA Docket 2005-22143-52

[3] Strashny, A., "The Role of Vertical Roof Intrusion and Post-Crash Headroom in Predicating Roof Contact Injuries to the Head, Neck or Face During FMVSS No. 216 Rollovers: An Updated Analysis," NHTSA Report No. DOT HS 810 847, October 2007.

[4] SNPRM, Table 2: 73 F.R. 5486.

[5] Friedman, D., "Roof Crush Versus Occupant Injury From 1988 to 1992 NASS" SAE 980210

[6] CFIR submission of February 25, 2008

[7] Brumbelow, M., "Roof Strength and Injury Risk in Rollover Crashes", IIHS, March 15, 2008 and
Lund, A., IIHS Status Report, Volume 43 No. 2, Comment to Docket 2008-0015

[8] Appendix, section D, of this submission, Malibu and JRS side window breakage and ejection injury potential data

[9] Appendix, section A, of this submission, JRS dynamic roof crush speed vs SWR

[10] Appendix, section C, of this submission, JRS data on diving

[11] Safety Analysis, Inc. submission and deposition testimony of Kenneth Orlowski Appendix Section A

[12] Appendix, Section B, of this submission,

[13] Center for Auto Safety submission to NHTSA docket 2008-0015

[14] Appendix, section E, of this submission, Malibu I rollcaged and production unbelted occupant data

[15] NHTSA Docket Comment 2008-0015, CFIR submission, February 25, 2008 submission pages 5 & 10

[16] Appendix, section E, of this submission, Correlation of IIHS side impact ratings and SWR, CAS / Nash analysis of Toyota NASS files, JRS test evaluation of 2007 Camry, Sonata and Chrysler 300.

[17] NHTSA Docket Comment 2008-0015, CFIR submission, February 25, 2008 submission pages 5,8,9,11-13

[18] Appendix, section F, of this submission, Significance, Data from February 25, 2008 submission, Corrections.

Appendix

A. *Roof Crush Speed Injury Potential and SWR*

A restrained occupant is likely to receive a head, face or neck injury only when seated in the front outboard seat on the initially trailing side of the vehicle that is rolling over. For such an occupant, the potential for head, face and neck injury is a function of both the extent and speed of roof crush. Dynamic testing is the only way to fully evaluate these aspects of roof performance in a rollover. Both the extent and speed of roof intrusion must be considered in adopting an optimal roof crush performance standard.

If NHTSA is committed to using a quasi-static test for determining compliance, it must stress the roof in a realistic manner which includes not only its vertical crush resistance, but its resistance to lateral, shear loads.

Most reputable experts in biomechanics agree [1][2]that the onset of serious head and neck injury occurs from an impact at 7 mph or more. At the time of roof impact, we know from the Malibu tests that the occupant may be moving toward the ground with a maximum vertical component of speed of 1 to 2 mph. Thus, during a rollover, the threshold roof intrusion speed for serious injury potential is around 6 mph. Figures 1 and 2 from the same tests as Figures 1 and 2 in the recent submission from Friedman and Nash indicate that far side, maximum dynamic measured roof crush speed at any point over the occupant seat is more than 6 mph for vehicles with SWR in FMVSS 216 less than 3.8. While an occupant can be under any point he is more likely to be somewhere between the A and B pillars and inboard of the roof rail.

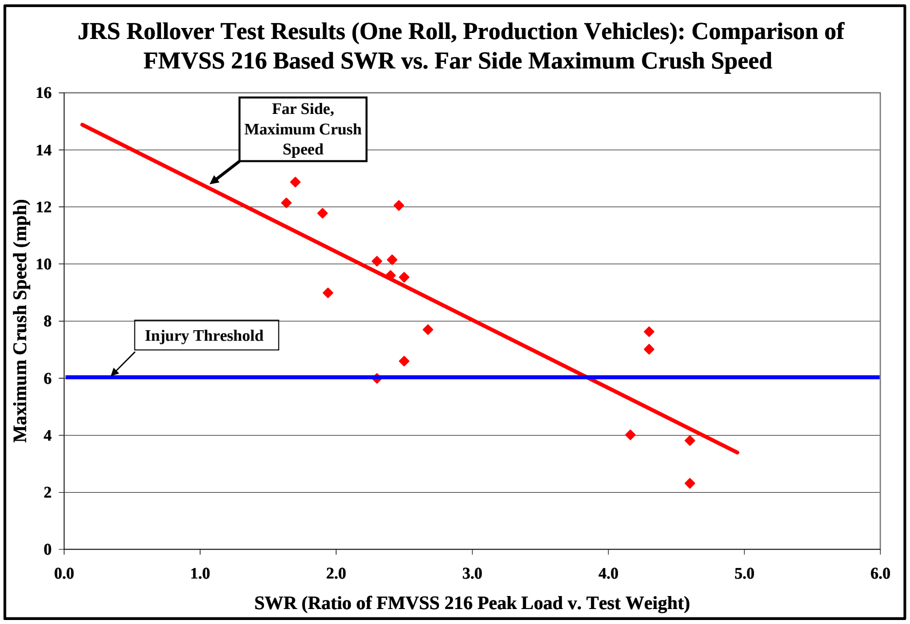

Figure 1: JRS one roll tests of 17 vehicles, relating maximum crush speed to FMVSS 216 SWR.

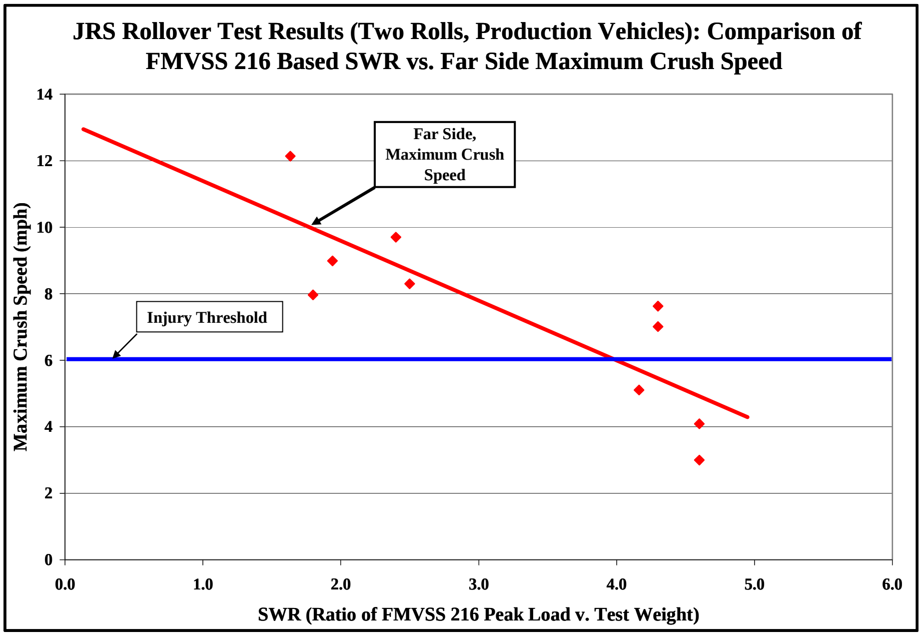

Figure 2: JRS two roll tests of 11 vehicles, relating maximum crush speed to SWR

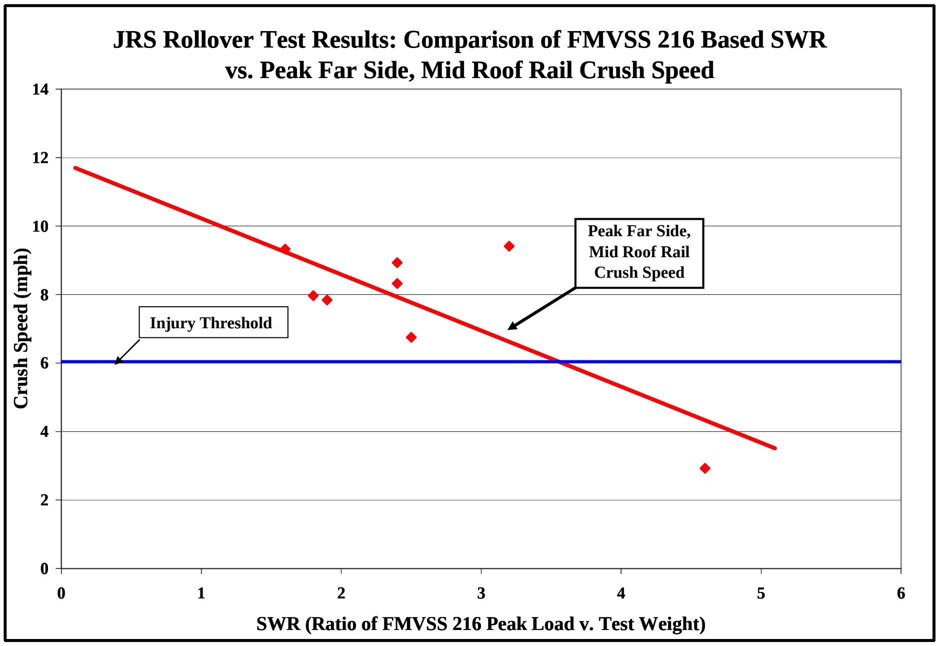

Figure 3. JRS tests of 8 vehicles with the same protocol showing peak far side mid-roof rail crush speed versus FMVSS 216 SWR

Figure 3 shows crush speed data from a set of JRS tests of 8 vehicles using a specific, standard protocol and measurements at the far side mid-roof rail. These data again indicate that intrusion speed is more than 6 mph for vehicles with an SWR of less than 3.5. It is important to note that the far side mid roof rail represents a typical position of a dummy's or an occupant's head in a rollover. However, in vehicles with weaker roofs the point of maximum roof crush speed is often at a buckle in the roof rail, windshield header, or roof panel. These buckles often intrude more and more rapidly than the corner of the roof over the A pillar.

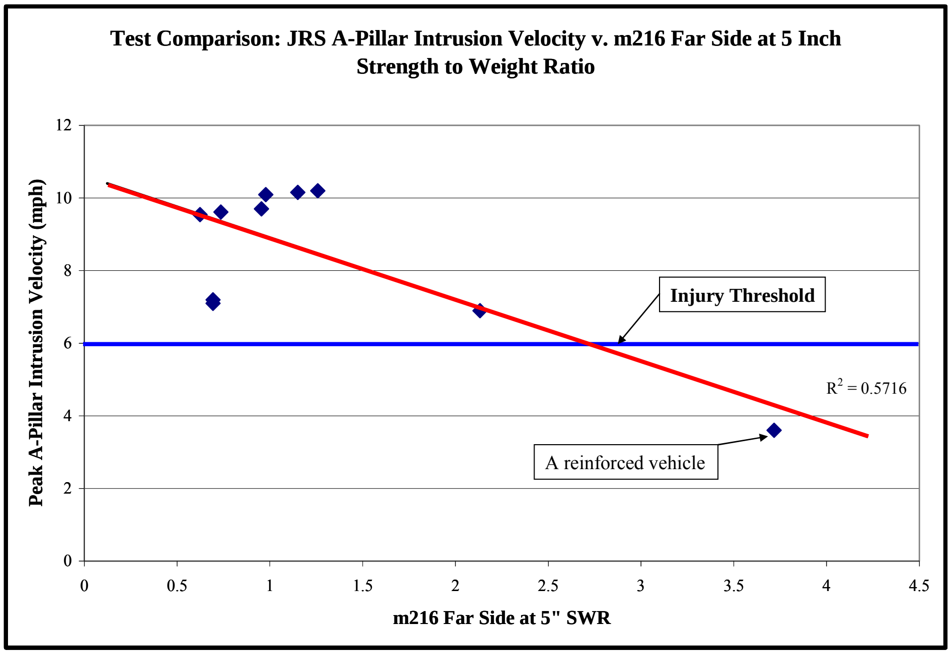

Figure 4. 10 JRS and M216 tested vehicles

Figure 4 shows data from tests of 10 vehicles for which JRS and M216 tests had been conducted. The M216 data for the far side was collected after a near side test at 10º pitch and 25º roll to 5”of crush. The far side data was then collected at 10º pitch and 40º roll angles to 5 inches of crush. The far side roof strength at 5” of crush was then divided by the test weight to determine the M216 far side SWR against which the peak A-pillar intrusion velocity was plotted. This data indicates that the 6 mph injury threshold of intrusion speed occurs with an M216 far side SWR of 2.7. This SWR criterion from this available data should be discounted to some degree for two considerations: 1) The strongest production vehicle tested (2004 XC90) is the point at SWR 2.2 and 2) The first side of a two sided test is expected to be at 5º pitch and 25º roll to 5”. NHTSA should do a second side test at 10º by 40º on the possibly stronger production 2006 XC90 they already tested to resolve the appropriate second side SWR criteria.

This experimental crush speed data from our JRS testing supports the validity of NHTSA’s post crash headroom analysis and provides a strong basis for establishing a first side (5º pitch and 25º roll) minimum SWR in FMVSS 216 at 3.5 (as indicated in the body of this submission) and a second side (10º pitch and 40º roll) minimum SWR of at least 2.0, both within 5 inches of platen displacement at maximum unloaded weight.

A submission to docket NHTSA-2005-22143 containing our November C*f*IR presentation to NHTSA responding to its request for information on JRS reliability, repeatability, and its ability to collect data on injury potential (injury measures in relation to real world accident circumstances) has not been posted to date. In our first submission to the new docket, dated February 25, 2008, we asked for acknowledgement of the acceptability of the JRS body of data or an indication of what additional supporting data is desired. We believe that the testing and data collection effort we have made and are continuing to assist NHTSA in its determinations warrants a timely response prior to NHTSA's final rulemaking NPRM and that request is herewith reiterated.

With respect to a causal relationship, Mr. Kenneth Orlowski of Safety Analysis, Inc., stated in his submission to this docket:

> "The Agency's referenced papers by Rains(1) and Strashny (2) do not in any way, establish a **causal** relationship between roof/pillar deformation and injury. One *cannot* derive or establish a **causal** relationship between roof/pillar deformation and occupant injury by analyzing accident data. Neither Rains, nor Strashny, attempt to evaluate similar rollover roof-to-ground impacts."

We have established the causal relationship between roof/pillar deformation and occupant injury with JRS dynamic rollover tests of production vehicles with SWRs ranging from 1.6 to 5.3. The results of these tests show that only vehicles with SWR above approximately 3.5 meet NHTSA's post crash criterion that the vehicle have positive headroom to substantially reduce the potential for fatal and incapacitating injury.

In an industry wide effort to thwart use of the JRS dynamic tests as a body of evidence, Dr. Edward Moffatt, Mr. Orlowski, Mr. G. S. Bahling and Mr. Michael James (representing GM, Ford, Chrysler, Nissan, Toyota and Honda) have claimed the JRS is not scientific, reliable, repeatable, nor accepted in the technical community and therefore cannot be used to validate statistical studies conducted by NHTSA and IIHS. In response, CfIR has supplied NHTSA with all requested accurate and validating test data on these subjects.

Mr. Orlowski also cites a 2002 Controlled Rollover Impact System (CRIS) dynamic Matched Pair Comparison Project testing three production vehicles with an SWR = 1.6 and three rollcaged vehicles with an SWR of at least 4.8. In this contrived comparison, the vehicle is dropped on its roof from an unrealistic height so that its first roof impact is at the point on the roof panel where the dummy's head is located so that the dummy neck registers a major diving injury regardless of what happens to the roof.

With respect to dynamic rollover test acceptability, Mr. Orlowski provided the following testimony in a *Jones v Honda* deposition. Honda's expert Kenneth Orlowski recognizes the advantages to dynamic testing such as the dolly rollover, CRIS or JRS:

Q: Okay. You see, my understanding is that a drop test is mostly static, in the sense that there is no rollover component.

A: Well, you're mixing up the terms.

Q: Because it's moving?

A: It's a dynamic impact,

Q: But the vehicle is not rolling; is that correct?

A: That's absolutely correct.

Q: And so was there some theory that the CRIS test would be more accurate because the vehicle was rolling?

A: It would be more accurate with respect to, let's say, the three velocity inputs that you have in a rollover versus a drop test. A drop test can isolate an impact situation with respect to all of those vector quantities, but you won't have, obviously, centrifugal force working on the vehicle, the roll dynamics of the vehicle or the occupant. So a CRIS test, like a dolly rollover test, certainly has horizontal speed, it has vertical velocity, and it has rotational rate or velocity. But for the first time, the problem with the dolly rollover test is that it was not repeatable with respect to specific roof-to-ground impacts. The CRIS test, the CRIS fixture allows for that repeatable first roof-to-ground impact.

Q: Okay

A: So now you can – as long as you hold the other variable constant [sic], like the horizontal velocity, the roll rate, and the vertical drop, and you have the same dummy position and the same dummy in each test, now you can compare onto one of the results.

The JRS test, like the dolly rollover test, certainly has horizontal speed, vertical velocity and rotational rate or velocity. It is also repeatable with respect to specific roof-to-ground impacts. As such, Orlowski recognizes that it is an improvement upon the dolly rollover test. Any criticisms he may have go to the weight of the evidence and not the admissibility.

Honda's expert further concedes that a dynamic test is not new science:

Q: But the CRIS test – basically, that's not new science. Basically, you're just – you just created a situation in which to try to more closely simulate the accident, is that correct?

A: The new science, if you will, was being able to repeat that in an actual rollover situation.

Q: Right. But the actual test itself is nothing other than an attempt to simulate the conditions that are existing in a rollover accident?

A: That's fair.

Q: Okay. And I'm not trying to minimize that, but frankly, that's just – I mean, that's not new science.

A: Well, actually, the laws of physics are not new science

Orlowski also recognizes the usefulness of other rollover tests:

Q: That there are other tests of roof strength under rollover or really simulated rollover scenarios that have been used over the years, either experimentally or in other contexts?

A: I can say that I'm aware of a lot of other rollover tests. I've been working – while I worked at GM, I was aware of every rollover test that was experimented with respect to procedures that they had performed.

Q: Okay.

A: I've seen many other attempts at repeatable rollover test methodology.

Q: And different tests may have different applicability; is that correct?

A: Sure. You study a rollover test for what it's worth.

Roof Crush Speed References:

[1] Nash, C.E., Friedman, D., "A Rollover Human/Dummy Head/Neck Injury Criteria," ESV Paper Number 07-0357.

[2] Sworn deposition testimony of Edward Moffatt, taken on February 26, 2007 in Basco vs. Toyota Motor Company*, page 137-139;*

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Line 20: Q. You've referred to this type of injury as a diving injury. Have you examined the typical stream, lake, swimming pool, diving type injuries, the mechanisms related to that?

A. I have not. I'm familiar with a number of papers regarding diving injuries. I think the most

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prominent being the MacAlheny paper. But there's a number of other papers of literally stream driving injuries. The point of this is not that it is like diving into a stream, but rather that it's a term that's used to describe a head stop, body keeps moving type of injury.

Q. With that being said, you've referenced, explicitly, diving injuries similar to when a swimmer dives into a shallow pool so I want to follow that correlation. Do you look at any data on what the average drop height is for an person diving into a pool that receives a neck injury?

A. I have not. But the MacAlheny paper that I referred to there did a study of 64 diving injuries, whether it's a pool or a creek or a mud, something. And then they reconstructed them by having people dive into swimming pools and look at the potential velocities available. And they came up with about an 18 inch drop, as -- which is roughly around seven miles an hour at the transition point of where the risk of significant neck injury really increases. But I have not personally done that. ...

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Line 15: Also, Myers and Nightingale, also at Duke University, did a number
of neck impacts -- or head impact studies fracturing necks and confirmed that
this seven miles an hour is about the point, transition point where the risk
of significant neck injury goes up.
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B. Correlation of Statistical and Experimental Injury Rate, Injury Potential and Injury Probability

In their latest rollover work, IIHS presented a trend line for fatal and incapacitating injuries based on state KABC0 data. This is illustrated in Figure 1 of their submission to this docket, 2008-0015.

In the 1998 through 2000 timeframe, NHTSA published "Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems". In that work NHTSA presented a function for the probability of injury based on Nij for AIS 3+ and AIS 5+ injuries as shown here in Figure 1, with Nij values from JRS testing. While these functions were developed based on frontal impacts and air bag studies, they are the only published neck injury criteria from NHTSA.

The Nij reference values are related to a dummy's upper neck load cell measurements and are considered unreliable and inappropriate for use in rollovers. An exception is Fz which interpreted as a measure of head impact speed. There appears to be a consensus that the onset of serious to fatal neck injury is at around 7 mph (and that is the way we have used it in evaluating roof intrusion speed injury potential) which, in Fz terms, is about twice the reference values in the Nij criteria. The Nij moment load term My at the upper neck load cell is hardly ever significant because of the aligned neck and the erect posture of the dummy. As is noted in the Strashny report, in 1994 Digges suggested that restrained occupants in a rollover were most likely to have potentially injurious contact with the roof with their necks already flexed.

An ongoing study, using a lateral high speed camera focused on the head/neck/torso for photo analysis, upper (for Fz) and lower (for My) neck load cells and a pre-flexed orientation of the lower neck relative to the torso, may yield more realistic and useful results.

Using our Nij data from tests with HIII 50th test dummies in vehicles with known SWRs and during the first roll or in a vehicle in good condition for the second roll with a standard dummy setup, we computed the probability of injury based on NHTSA injury criteria data. The correlation is very high with the IIHS published injury rate as a function of SWR. However, these tests are with a far side impact starting at about 190 degrees, where neck injuries are likely and would increase the probability of neck injury. On the other hand neck injury should be a small percentage of the injury rate seen in the IIHS study of all impact configurations and injury types. At this point, there is no known relation to directly compare the IIHS and NHTSA injury criteria based rates. What is important and noteworthy is that both trend lines illustrate a reduced chance of injury with increasing roof strength.

We are attempting to develop a head and neck injury potential correlation with the IIHS injury risk plot versus SWR and JRS test results. As indicated previously, the trend lines are nearly parallel notwithstanding the inappropriateness of the Nij measurements and reference values and that the JRS data is at similar test configurations and not representative of all types of rollovers seen in the statistical databases.

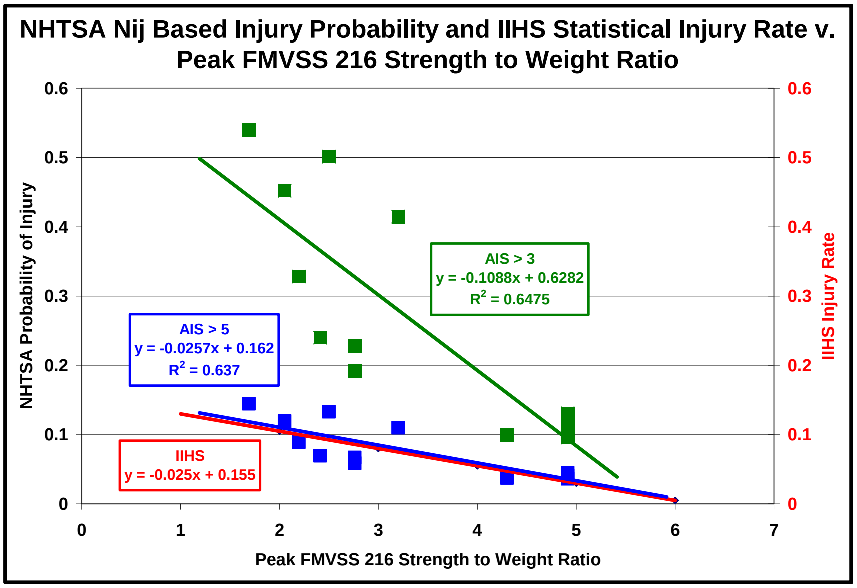


Figure 1. NHTSA Probability of injury for AIS =3+ and AIS =5

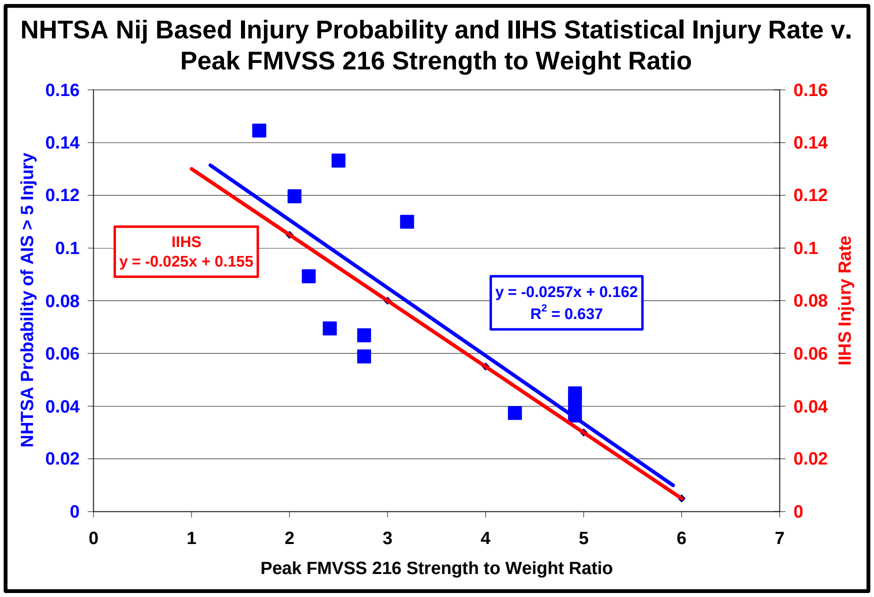


Figure 2. Comparison of NHTSA injury probability, IIHS Injury rate with Nij results from JRS tests as a function of FMVSS 216 SWR

C. Diving Data Analysis

A particularly dangerous aspect of a rollover is the interaction of the vehicle roof and the occupant which can lead to injurious forces being applied to the head and neck. Moffatt and others have hypothesized that in the inertial frame of reference, the roof panel and the occupant dive into the ground such that roof strength is immaterial (much like diving into a swimming pool [1]). The present study uses physical measurements recorded in JRS dynamic rollover tests to compare the impact speed of the dummy with the roof (relative to the floor) of the vehicle and the speed of the center of mass of the vehicle (at the time of maximum structural intrusion speed and at the time of peak neck load). Six vehicles were tested. One vehicle had a reinforced roof, one vehicle had a relatively strong roof, and two had weaker roofs. Two additional vehicles were added to the original study exploring variations in dummy size and performance during the second roll of a two-roll sequence.

A 50 % male Hybrid III ATD was placed in the driver's seat (far side position, shown in Figure 1) of a 1993 Jeep Grande Cherokee, a 1999 Jeep Grand Cherokee, a 1998 Mercedes Benz ML 320, a 1998 Chevrolet Blazer and a 2004 Subaru Forrester. A 5% female Hybrid III ATD was placed in a 1996 Isuzu Rodeo.

Figure 1 Showing typical setup.

The Blazer had its roof reinforced [2]. The dummy was restrained by the available lap and shoulder belt. A string potentiometer attached to the buttocks of the dummy recorded its movement towards the roof of the vehicle. The test parameters are shown in Table 1.

TABLE 1 - TEST PARAMETERS

Measurements	1993 Jeep Grand Cherokee	1999 Jeep Grand Cherokee	1998 Mercedes ML 320	1998 Chevrolet Blazer (reinforced roof)	1996 Isuzu Rodeo (5% dummy)	2004 Subaru Forrester (Roll 2)
Platform speed at impact (mph)	18	17.4	17.4	15.5	18	12.7
Pitch attitude of vehicle (degrees)	9.9	10.3	10.0	10.1	9.8	11.1
Drop height above JRS road platform (in)	5	5	5.4	4	4.2	4.3
Rotation rate (degrees/sec)	244	257	231	203	240	139
Approximate rotation rate at far side impact (degrees/sec)	266	279	279	324	279	260
Approximate Peripheral speed at far side impact (mph)	10.8	11.4	11.5	12.7	10.6	9.9
Rotation angle at roof contact with platform (degrees)	148	147	144	151	153	150

Starting from an upright position, the vehicle was rotated passenger side down and dropped from an average height of 4.7 inches onto a rigid platform (roadway) moving under the vehicle at an average speed of 16.5 mph.

The vehicles were rotated with an average nose-down pitch of 10 degrees and an average rotation rate of 219 degrees/sec. The vehicles contacted the platform at an average rotation angle of 149 degrees (near side impact) then rolled onto the left side and engaged in the far side impact where the dummy was seated. Data were collected for dummy movement as a function of roll angle and time. Data were also recorded for the roll angle of the vehicle, neck forces and moments, and platform forces (roadway load). A-pillar and B-pillar displacement were measured radially from a longitudinal axis through the center of gravity of the vehicle.

The vehicle was suspended along a longitudinal axis running through its center of gravity. String potentiometers attached to the front and rear rolling axis points measured the vertical displacement of each end of the vehicle during the test. The vertical speed of the center of gravity was calculated as a proportion of the vertical displacement of the front and rear drop displacement. Center of gravity (CG) for each vehicle was obtained from published specifications. The tests were performed on the JRS, a precision repeatable controlled dynamic rollover roof test fixture [3]. Data from the dummy were collected at 10 KHz and filtered to SAE Class 60. Fixture data were collected at 1 Khz.

Results show the dummy initially moves towards the vehicle roof (away from the seat) at about 1 mph. Then, during the roof crush phase, the dummy is pushed towards the seat at 4 to 6 mph in the vehicles with production roofs.

Table 2 compares the ground referenced CG falling speed with measured structural (roof rail) intrusion speed. In cases where the roof panel buckled more aggressively than the roof rail (to which the string pots were attached), intrusion speed was derived from dummy load data. These derived intrusion rates are presented in Table 3.

Results - Table 2

Measurements	**1993 Jeep Grand Cherokee**	**1999 Jeep Grand Cherokee**	**1998 Mercedes ML-320**	**1998 Chevrolet Blazer (Reinforced Roof)**	**1996 Isuzu Rodeo (5% dummy)**	**2004 Subaru Forrester (Roll 2)**
At Max CG Falling Speed						
Dummy Falling Speed (mph)	0.5	0.4	0.7	0.9	1.3	0.9
CG Falling Speed (mph)	4.3	4.1	4.7	5.0	3.9	2.7
Ground Reference Speed	**4.8**	**4.5**	**5.4**	**5.9**	**5.2**	**3.6**
A pillar Speed (mph)	4.5	4.5	4.9	5.8	3.5	4.4
B pillar Speed (mph)	3.7	3.7	4.0	3.4	4.2	3.0
Average Interior Speed Between Pillars (mph)	4.1	4.1	4.4	4.6	3.8	3.7
Average Interior + Dummy falling = Closing Speed	4.6	4.5	5.1	5.5	5.1	4.6
Difference between Interior Closing Reference Speed and CG Ground Reference Speed	**-0.2**	**0**	**-0.3**	**-0.4**	**-0.1**	**1.0**

Results - Table 3

Measurements	**1993 Jeep Grand Cherokee**	**1999 Jeep Grand Cherokee**	**1998 Mercedes ML-320**	**1998 Chevrolet Blazer (Reinforced Roof)**	**1996 Isuzu Rodeo (5% dummy)**	**2004 Subaru Forrester (Roll 2)**
Ground Reference						
Dummy Falling Speed (mph)	0.5	0.4	0.7	0.9	1.3	0.9
CG Falling Speed at Max Neck Load (mph)	3.0	3.8	2.7	3.7	4.2	2.0
Dummy Falling Speed at Max Neck Load (mph)	**3.5**	**4.2**	**3.4**	**4.6**	**5.5**	**2.9**
At Max Dummy Neck load time and position						
Impact Force Fz (N)	9960	8750	4650	5360	5337	4202
Calculated Impact Speed from neck force (mph)	**9.2**	**8.0**	**4.3**	**5.0**	**4.9**	**3.9**
Difference including buckles (mph)	**5.7**	**3.8**	**0.9**	**0.3**	**-0.6**	**1.0**

The results are shown in Table 2 for a comparison of ground referenced CG falling speed with measured structural (on the roof rail) intrusion speed and in Table 3 with dummy measured intrusion speed (where the roof panel buckle intrusion affected the dummy striking speed). In all cases, except where there was a significant roof panel buckle, the difference between ground reference speed and interior measurement speeds was ± 1 mph.

The Max Ground Reference Speed for the dummy is the sum of the dummy falling speed at contact (relative to the vehicle), the peripheral speed (as reflected in conjunction with the CG), and the falling speed of the vehicle CG. Note at the critical time (when the pillars and roof are crushing), the crush point of the roof is moving below the CG, so the peripheral velocity of the vehicle is becoming parallel to the ground.

A simple analogy is the playground slide where a child is happy to start down a 10' high playground slide because she intuitively understands that while dropping through 10' toward the ground, the slide will slow her approach during the last moments by converting her trajectory to one that is almost parallel to the ground. In exactly the same way, at 90 degrees, the peripheral speed of a rolling vehicle may be significant, but by the time the ground collision occurs, the peripheral velocity vector is essentially parallel to the ground and thus does not contribute to the impact.

The structural intrusion speed of the roof structure at the location of the dummy is estimated by averaging the intrusion speeds of the A and B pillars. The maximum interior structural reference speed is calculated by adding the dummy falling speed. Structural intrusion speed refers intrusion of the structural members. Roof panel buckling adds an additional component to the intrusion.

Comparing the max interior structural reference speed and the max ground reference speed shows them to be very close. This indicates the dummy falling speed measured by the CG descent or structural deformation is equivalent.

We also calculated the impact speed of the dummy with the roof at the time of max neck force (Fz) [4]. Using this formula, the dummy struck the 1998 Mercedes roof at 4.3 mph and the dummy struck the 1998 Blazer reinforced roof at 5 mph. These two tests yield a dummy impact speed consistent with the impact calculated from CG motion and dummy falling speed. The dummy impact speed based on neck force, was markedly higher in the 1993 and 1999 Grand Cherokees. In these vehicles, the dummy impact calculated from neck forces was 9.2 mph and 8.1 mph which is substantially higher than that predicted from the CG falling speed and dummy falling speed.

Examination of the Grand Cherokee roofs showed them to have a buckle in the roof panel over the driver's seating position as shown in the photo. The buckle, interacting with the dummy, markedly increases the neck force (see Figure 2 and 3).

Figure 2 showing 1999 Grand Cherokee with roof buckle

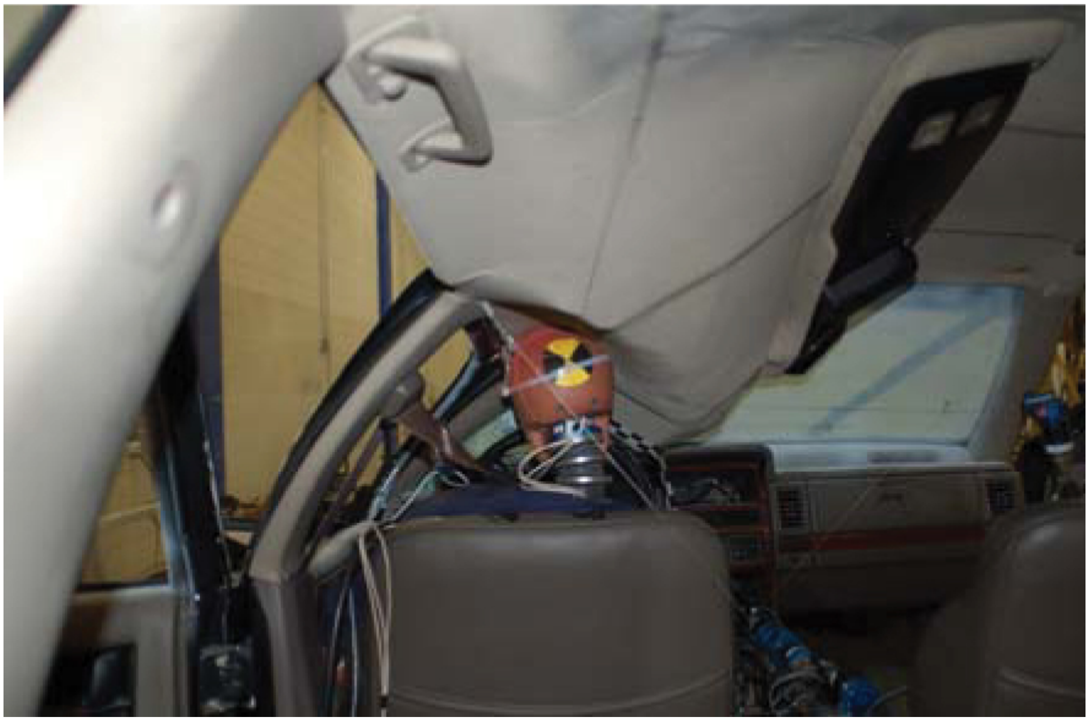


Figure 3 showing 1999 Grand Cherokee roof buckle and dummy

In conclusion, in each of the tests the maximum velocity of the center of gravity of the vehicle as it was dropped was approximately equal to the average of the intrusion speeds of the A and B pillars. The impact speed to the dummy was also comparable to the CG ground reference speed and the structural reference speed except for the weak roofs which also exhibited a marked roof panel buckle.

The tests document the complexity of the motions of the dummy, pillars, and the CG of the vehicle during a rollover. During the roof crush phase, portions of the vehicle structure may move at speeds higher than the roof crush speed. For example, two production vehicles (1993 and 1999 Grand Cherokees), showed a marked intrusion into the occupant space in the form of a buckle during the rollover

Diving references:

[1] Bahling, G., et. al.: “Rollover Drop Tests – The Influence of Roof Strength On Injury Mechanics Using Belted Dummies.” SAE paper 902314, 1990.

[2] Herbst, Brian; Forrest, Stephen; Meyer, Steven E.; Hock, Davis: “Alternative Roof Crush Resistance Testing with Production and Reinforced Roof Structures.” SAE Technical Paper 2002-01-2076

[3] Friedman, D; Jordan, A; Nash, C; et. al.: “Repeatable Dynamic Rollover Roof Test Fixture.” Proceedings of IMECE03 2003 ASME International Mechanical Engineering Congress & Exposition Washington, DC, November 16-21, 2003, IMECE2003-43076

[4] Nash, Carl E.; Friedman, Donald: “A Rollover Human/Dummy Head/Neck Injury Criteria.” 2007 Conference in Experimental Safety Vehicles, Paper Number 07-0357.

D. Ejection and Unrestrained Occupant Injury Potential

NASS researchers often assume that ejected occupants receive their injuries outside the vehicle. This has led NHTSA to assume that ejected occupants would not benefit from greater roof crush resistance and that keeping unrestrained and ejected occupants inside the vehicle will virtually eliminate about 3000 deaths and 6,000 serious injuries.

Our investigations of rollovers with occupants ejected from vehicles that do not comply with FMVSS 201 upper interior padding requirements have often found significant witness mark on the headliner or around the exit portal from contact prior to ejection. In many cases, we have determined that a major injury occurred inside the vehicle prior to ejection.

The point here is that there is insufficient field accident data to support the assumption that keeping occupants inside will fully produce these benefits. CfIR in earlier docket submissions did report on NASS analyses of ejections, with rhetorical comments on mitigation. [1] There is now sufficient experimental data to recognize that increased roof SWR beyond 3.5 will minimize portal creation and ejection potential and will dramatically, in conjunction with FMVSS 201 implementation, reduce serious to fatal injury in rollovers.

The data comes from two sources: the 16 Malibu tests of the eighties divided into a production SWR = 2.2 and roll caged SWR=7 groups; and 19 JRS tests of production vehicles of various SWR, tested with different but generally representative real world protocols. Data were collected by inspecting the video films of the tests and determining whether the front seat side windows broke on the first or the second roll. The specific interest in the first and second roll comes from NHTSA NASS data indicating that 65% of rollovers and 50% of serious to fatal injuries (including ejections) occur in one roll events and that cumulatively, about 95% of the rollovers and 95% of the serious injuries occur within two rolls.

The Malibu data are shown in Table 1 and indicate that in the production vehicles five tempered front side windows broke while only two broke in the roll caged vehicles in the first roll. In the second roll three additional windows broke in the production vehicle and none broke in the roll caged vehicles. This would suggest that, with stronger roofs, ejection portals might be reduced fourfold.

The JRS production vehicle data collection is shown in Table 2 & 3. None of these vehicles was modified to retain or protect the side window glazing. Specifically it shows a dramatic reduction in tempered window breakage above an SWR of about 3.5.

In 21 JRS one roll tests, 13 vehicles with an SWR less than 3.5, broke fourteen front side tempered windows. In the other eight vehicles with an SWR greater than 3.5 only 2 windows broke for a reduction in front seat ejection injury potential of about four. In addition, 13 rear side windows broke (and two doors opened) in the SWR < 3.5 group but no additional windows broke in the SWR > 3.5 group. This suggests as much as an eightfold reduction in front and rear seat ejection injury potential. With roof strength increased above a SWR of 3.5, there is a likelihood of reducing ejection injury.

Table 1. Side window breakage in the production Malibu dolly rollover tests.

Model Years	Test Label	SWR	Front Side Window Breakage 1st Roll	Additional Window Breakage 2nd Roll	Front side window breakage after two rolls
	Malibu I & II Production				
1978-1983	1983 Chevrolet Malibu I - Test 1	2.2	Driver's	Passenger's	Driver's & Passenger's
1978-1983	1983 Chevrolet Malibu I - Test 4	2.2	Passenger's	None	Passenger's
1978-1983	1983 Chevrolet Malibu I - Test 5	2.2	Driver's	Passenger's	Driver's & Passenger's
1978-1983	1983 Chevrolet Malibu I - Test 8	2.2	Driver's	None	Driver's
1978-1983	1983 Chevrolet Malibu II - Test 3	2.2	None	Driver's	Driver's
1978-1983	1983 Chevrolet Malibu II - Test 4	2.2	Driver's	None	Driver's
1978-1983	1983 Chevrolet Malibu II - Test 7	2.2	None	None	None
1978-1983	1983 Chevrolet Malibu II - Test 8	2.2	None	None	None
Totals			5	3	8

Model Years	Test Label	SWR	Front Side Window Breakage 1st Roll	Additional Window Breakage 2nd Roll	Front side window breakage after two rolls
	Malibu I & II Roll-caged				
1978-1983	1983 Chevrolet Malibu I - Test 2	7	None	None	None
1978-1983	1983 Chevrolet Malibu I - Test 3	7	None	None	None
1978-1983	1983 Chevrolet Malibu I - Test 6	7	None	None	None
1978-1983	1983 Chevrolet Malibu I - Test 7	7	None	None	None
1978-1983	1983 Chevrolet Malibu II - Test 1	7	Driver's	None	Driver's
1978-1983	1983 Chevrolet Malibu II - Test 2	7	Driver's	None	Driver's
1978-1983	1983 Chevrolet Malibu II - Test 5	7	None	None	None
1978-1983	1983 Chevrolet Malibu II - Test 6	7	None	None	None
Totals			2	0	2
Ratios			2.5 to 1	3.0 to 0	4 to 1

Table 2. Side window breakage in the roll caged Malibu dolly rollover tests.

Model Years	Test Label	VIN	SWR	Total Window Breakage 1st Roll	Front Side Window Breakage 1st Roll	Additional Window Breakage 2nd Roll
	SUVs					
1991-1997	1996 Isuzo Rodeo - SUV	4S2CK58V8T4320589	1.6	1st and 2nd windows on Driver's side = 2	Driver's	No 2nd Roll
1995-2001	2000 GMC Jimmy - SUV	1GKCS18W0YK263065	1.6	1st and 2nd windows on Driver's side = 2	Driver's	No 2nd Roll
1995-2001	2000 Ford Explorer - SUV	1FMZU72X1YUB59799	1.6	Front and rear windows on Both sides = 4	Driver's & Passenger's	None
1999-2004	1999 Jeep Grand Cherokee - SUV	1J4GW58N7XC771665	1.7	1st and 2nd windows on Driver's side = 2	Driver's	No 2nd Roll
1993-1998	1993 Jeep Grand Cherokee - SUV	1J4GZ78S8PC127231	1.8	1st and 2nd windows on Driver's side = 2	Driver's	No 2nd Roll
2003-2006	2003 Kia Sorento - SUV	KNDJD733835083630	1.9	Front and rear windows on Both sides = 4	Driver's & Passenger's	None
1995-2005	1998 Chevrolet S10 Blazer - SUV	1GNCS18WXWK251783	2.4	1st & 3rd Windows on Driver's side =2	Driver's	No 2nd Roll
2000-2006	2001 Chevrolet Suburban C1500 - SUV	3GNEC16T01G261346	2.7	1st and 2nd windows on Driver's side = 2	Driver's	No 2nd Roll
	Automobiles					
1995-2005	1997 Chevrolet Cavalier - Auto	1G1JF12TV7160736	2.3	1st and 2nd windows on Driver's side = 2	Driver's	None
1995-2005	1997 Chevrolet Cavalier - Auto	1G1JC1244V7103284	2.3	1st and 2nd windows on Driver's side = 2	Driver's	No 2nd Roll
1995-2005	1997 Acura CL - Auto	19UYA1255VL012375	2.4	1st and 2nd windows on Driver's side = 2	Driver's	None
1994-1999	1991 Mitsubishi Eclipse - Auto	4A3CS34T7ME143286	2.5	Driver's Side Front = 1	Driver's	No 2nd Roll
2006-	2006 Hyundai Sonata - Auto	KMHEU46C86A101711	3.2	No Window breakage = 0	None	Driver's
Totals	**13 Vehicles Tested**			**27 Side Window Broken**	**14 Front Side Window Broken**	**1 Front Side Window Broken**

Table 3. Side window breakage in JRS Tests.

Model Years	Test Label	VIN	SWR	Total Window Breakage 1st Roll	Front Side Window Breakage 1st Roll	Additional Window Breakage 2nd Roll
	SUVs					
2002-2006	2004 Volvo XC90 (White) - SUV	YV1CZ91H941075463	3.6	No Window breakage = 0	None	None
1998-2006	2003 Subaru Forester 2 - SUV	JF1SG63653H733406	4.3	No Window breakage = 0	None	Driver's
1998-2006	2004 Subaru Forester - SUV	JF1SG63634H718114	5.1	Driver's Side Front = 1	Driver's	None
1995-2005	1998 Chevrolet S10 Blazer - Reinforced - SUV	1GNCS18W1WK209614	> 3.5	Driver's Side Front = 1	Driver's	None
	Automobiles					
1998-2002	2002 Toyota Corolla - Auto	1NXBR12E22Z630655	4.2	No Window breakage = 0	None	None
2007-	2007 Toyota Camry - Auto	4T1BE46K77U028757	4.3	No Window breakage = 0	None	None
1995-2005	1998 Acura CL - Reinforced - Auto	19UYA154WL006629	> 3.5	No Window breakage = 0	None	None
1995-1999	1998 Nissan Sentra - Reinforced-Auto	321AB41DXWL054573	> 3.5	No Window breakage = 0	None	None
Totals	**8 Vehicles Tested**			**2 Side Window Broken**	**2 Front Side Window Broken**	**1 Front Side Window Broken**
Ratios				**8.3 to 1**	**4.3 to 1**	**3.1 to 1 after second roll**

The Malibu data also provide a source for unrestrained injury potential. There were 94 potentially injurious impacts in the two series of vehicles as shown in the charts of Appendix Section E. Malibu I consists of eight vehicle tests of two front seat unrestrained dummies, four of which were production vehicles and four were rollcaged. There were no injurious Pii's of the 27 Pii's to dummies in rollcaged vehicles and there were three injurious Pii's of the 26 Pii's in the production vehicles.

Ejection References:

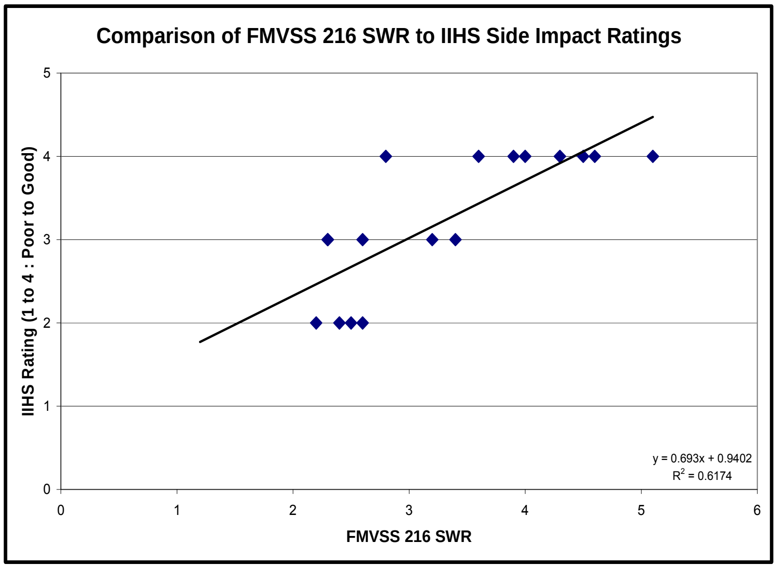
[1] Submission to NHTSA Docket 1999-5572-097 by Don Friedman and Carl Nash on August 31, 2004; Submission to NHTSA Docket 2005-22143-160 by Don Friedman on November 21, 2005

E. Structural and Cost analysis

Here we refer first to the CAS submission to this docket which includes a NASS analysis by Carl Nash, Ph.D. analyzing all Toyota rollover cases involving 2003 and later models on the assumption that Toyota has designed the roofs of most models on the same principle as the Corolla and Camry (strong A and B pillars and roof rails, weak windshield header). He found 37 cases of relatively straightforward Toyota car and light truck rollovers (i.e. no roof impact with trees, etc.). Very few of them had significant damage to the roof pillars or rails, but half had buckled or tented windshield headers. His paper on this subject, shows that the FMVSS 216 test is not adequate to pick up this type of roof weakness and that a sequential second side test at 10 x 40 is necessary.
Three JRS tests sponsored by the Santos Foundation through the Center for Auto Safety have been conducted on 2007 vehicle models: a Toyota Camry with a SWR of 4.3, a Hyundai Sonata at 3.2, and a Chrysler 300 at 2.5. These show the relationship between crush, crush speed and ejection injury potential and SWR some in modern cars. The data show that there is a clear and substantial improvement in all potential injury metrics at about the SWR 3.5 level.

The cost of upgrading FMVSS 216 to various SWR levels has been studied by NHTSA by analyzing the changes required in four vehicles of the pre 2002 model year generation and by reference to self-serving submissions by the Alliance of Automobile Manufacturers indicating a resulting large cost and weight penalty. In our last submission we detailed the cost and weight data and the testimony of a Toyota representative on improved structural strength in the Toyota Corolla. That submission suggested that the structural improvements in the Corolla were motivated by of the company's desire to improve side impact protection, not for improved roof SWR.

In an effort to present a broader data perspective, we extend that suggestion to an analysis of the relationship between IIHS side impact ratings and SWR. The chart of Figure 1 shows good correlation with a significant number of vehicles, indicating that only part of the cost or weight involved in improving roof structures should be assigned to upgrading FMVSS 216 since manufacturers are mostly doing it to upgrade side impact ratings.



F. Miscellaneous comments and corrections

Small sample sizes and specificity of claims

Certain of the data bases in this submission are small and the claims may seem like an unwarranted direct jump to generalize the SWR criteria (SWR ≥ 3.5). However, when the JRS results are considered collectively with NHTSA, IIHS, NCAC and other data the general relationship between FMVSS 216 SWR and the dynamic metrics of roof crush, they provide a compelling case that roof crush speed and ejection potential are critical factors in reducing rollover injuries. Further, there is no contravening data and the Agency has the resources to gather additional data to confirm the claims.

Unrestrained occupant injury

The production Malibu SWR is 2.2, about the average of the existing fleet. There were 3 excessive Pii injury criteria in 4 production Malibus (plus one complete windshield ejection without injury measure) and none in the four rollcaged Malibu's. The sample size isn't large but the data support the results of other tests and data analyses.

Chart of production Malibu vertical speed

This chart, first assembled in 1994 from the 1985 Malibu paper, here corrected with production angular roll rates and near and far side roof contact events, identifies and quantifies important but obvious attributes of a vehicles interaction with the ground. Specifically, it shows that the vehicle roll rate increases from trip during the first roll, as the vehicle slows its horizontal speed. This continues as the near side roof first contacts the earth with a minimal vertical velocity. That contact and the subsequent far side contacts continue to slow the vehicle and increase the roll rate. In JRS tests, in accordance with the laws of physics, the vehicle is constrained from moving laterally by the support towers and therefore slows the comparable weight roadbed, while the roadbed increases the vehicle's roll rate. As indicated in the chart, the vehicle or road speed decreases by about 3 mph for each of the two contacts and the vehicle's roll rate or peripheral speed increases by about 20 to 30% depending on friction.

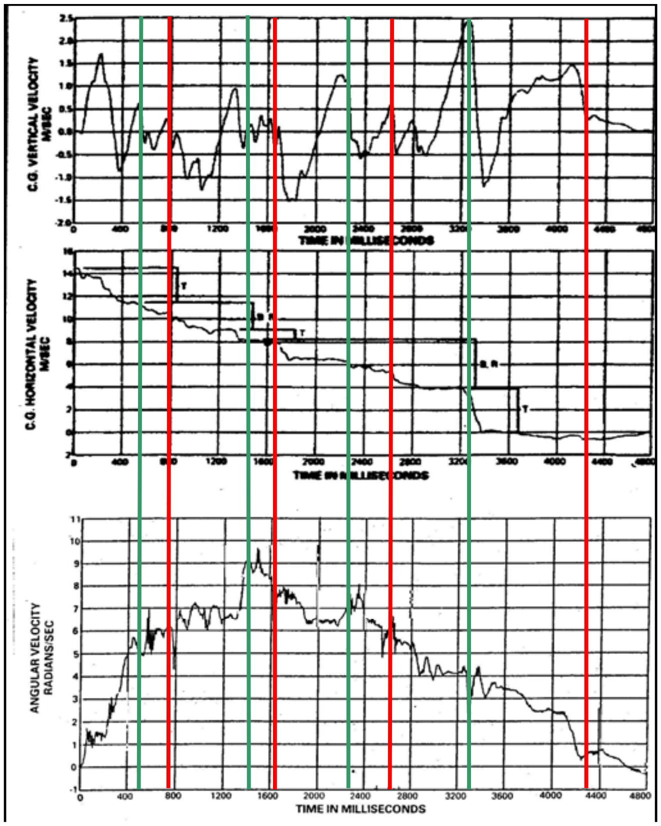
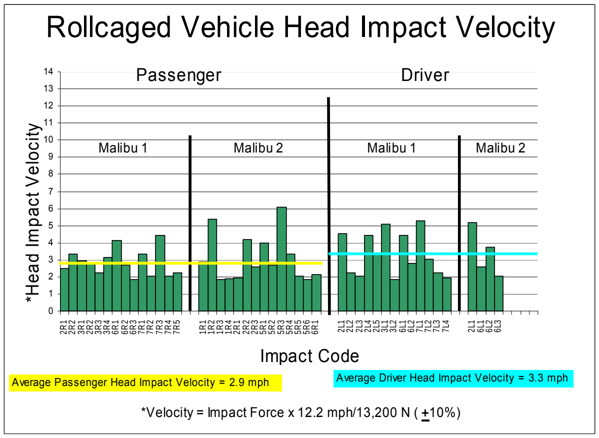


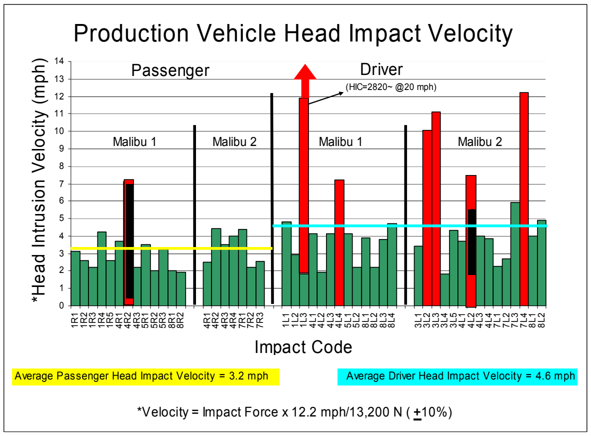
Figure 3. The typical vertical velocities of Test 5, a production roofed vehicle.

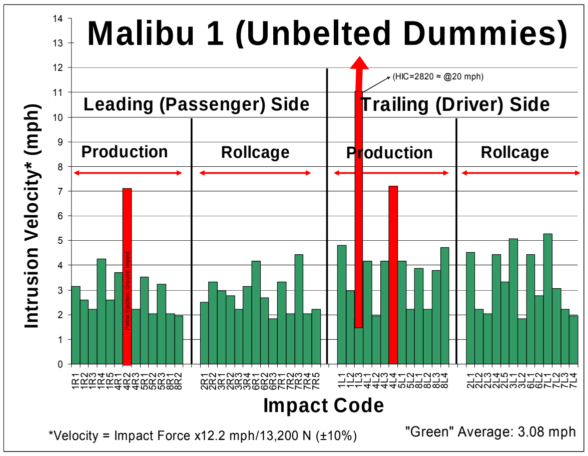
GM Malibu I
Test 5
(All data from GM Discovery)
Near Side Contacts:
(Green Lines)
550 ms = 0.6 mph
1500 ms = 0.3 mph
2350 ms = 1.2 mph
3350 ms = 1.2 mph
Far Side Contacts:
(Red Lines)
790 ms = 0.6 mph
1677 ms = 0.4 mph
2662 ms = 1.2 mph
4330 ms = 0.7 mph

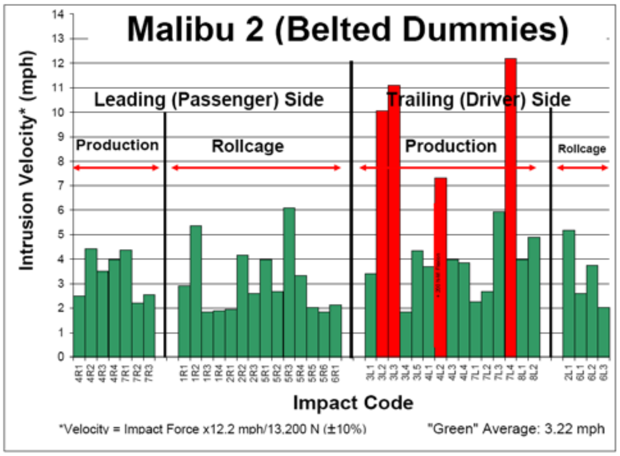
Malibu Pii charts with corrected averages

These charts, also assembled from the Malibu papers and data, has been used in four forms: with the force of all Malibu rollcaged Piis and the force of all production Piis; as well as the calibrated speed of those same Piis for production and roll caged vehicles. Previously, the averages were calculated without noting the Piis included, here corrected. The same charts have been displayed in the format of the separate Malibu I and Malibu II driver and passenger Piis in roll caged and production vehicles. The four corrected velocity charts are displayed here.


Rollcaged Vehicle Head Impact Velocity
Passenger
Driver
Malibu 1
Malibu 2
Malibu 1
Malibu 2
*Head Impact Velocity
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Impact Code
Average Passenger Head Impact Velocity = 2.9 mph
Average Driver Head Impact Velocity = 3.3 mph
*Velocity = Impact Force x 12.2 mph/13,200 N (±10%)


Production Vehicle Head Impact Velocity
Passenger
Driver
(HIC=2820~ @20 mph)
Malibu 1
Malibu 2
Malibu 1
Malibu 2
*Head Intrusion Velocity (mph)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Impact Code
Average Passenger Head Impact Velocity = 3.2 mph
Average Driver Head Impact Velocity = 4.6 mph
*Velocity = Impact Force x 12.2 mph/13,200 N (±10%)


Malibu 1 (Unbelted Dummies)
(HIC=2820 = @20 mph)
Leading (Passenger) Side
Trailing (Driver) Side
Production
Rollcage
Production
Rollcage
Intrusion Velocity* (mph)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Impact Code
*Velocity = Impact Force x12.2 mph/13,200 N (±10%)
"Green" Average: 3.08 mph


Malibu 2 (Belted Dummies)
Leading (Passenger) Side
Trailing (Driver) Side
Production
Rollcage
Production
Rollcage
Intrusion Velocity* (mph)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Impact Code
*Velocity = Impact Force x12.2 mph/13,200 N (±10%)
"Green" Average: 3.22 mph