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THE EFFECT OF STATIC ROOF CRUSH TESTS RELATIVE TO REAL WORLD ROLLOVER INJURY POTENTIAL

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ABSTRACT

Rollover crashworthiness for passenger vehicles is currently evaluated by the Federal Motor Vehicle Safety Standard (FMVSS) 216 static roof strength compliance test. However, research clearly shows that the static test is inadequate in evaluating a vehicle's injury potential performance in a real-world rollover event. Studies previously conducted by the Insurance Institute for Highway Safety (IIHS) show a general relationship between a vehicle's Strength-to-Weight-Ratio (SWR) and its real world injury potential. Although this general relationship is fairly accurate for most vehicles, there are many individual vehicle anomalies. The real world injury performance of the vehicles which make up these anomalies depends much less on the static roof strength (as measured in a FMVSS 216 test) and more on the dynamic performance of the roof and occupant protection systems during a real world rollover (as simulated on the Jordan Rollover System [JRS]). Repeatable dynamic crash tests are used by IIHS, National Highway Traffic Safety Administration (NHTSA), and the New Car Assessment Program (NCAP) to evaluate the performance of a vehicle in every major crash mode except rollovers. Dynamic tests represent the real world effect of vehicle dynamics, orientation, geometry, roof strength, occupant position and kinematics, restraint and other safety system effectiveness while directly measuring comparative dummy injury criteria. Because National Accident Sampling System (NASS) investigations can only measure the cumulative effect of post crash roof crush, NHTSA has established an empirical relationship that a vehicle with post crash negative headroom (PCNH) is five times more likely to injure the occupant. However, data indicates that the anomalies in head, neck, and spinal cord injury are related to the momentum exchange of dynamic head impact speed and the duration of neck loading in each roll, not the cumulative amount of residual roof crush. This paper suggests a means of comparatively evaluating a vehicle's dynamic rollover occupant injury potential performance.

INTRODUCTION

National Highway Traffic Safety Administration (NHTSA) and Insurance Institute for Highway Safety (IIHS) both use a static test to set vehicle roof strength performance standards and to predict the vehicle roof's ability to reduce dynamically initiated serious injuries and deaths. The static test ignores the dynamic non-linearity of buckles, alternate structural designs and geometry, belts, padding, and other safety systems. The FMVSS 216 static test standard has been in existence for 35 years and has had little or no effect on casualties. Doubling it from an SWR of 1.5 to 3.0 is expected by NHTSA to reduce roll occupant casualties by 1.5% when mostly implemented in the fleet by 2025. Using the Jordan Rollover System (JRS) dynamic rollover tests of 40 production vehicles ordered by NHTSA injury risk, comparisons were made with static tests and with dummy injury measures. This study provides a basis to consider the probable affect on casualties of the revised static FMVSS 216 Roof Crush Final Rule as compared to the casualty reduction of a real world dynamic rollover compliance test. A rough approximation is possible by normalizing the various related protocols used in 40 production vehicles. To make this comparison, it is necessary to first convert the effect of NHTSA's static SWR = 3+ rule into an injury risk evaluation of representative vehicles of the current fleet using NHTSA's own statistically validated post crash negative headroom criteria. Second, it is necessary to evaluate the relationship between injury risk and strength to weight ratio (SWR) to see how well SWR predicts performance and whether there are anomalies. Similarly, comparisons should be made of injury risk and dummy injury measures and the anomalies should be analyzed.

BACKGROUND

In 1970, National Transportation Safety Board (NTSB) proposed a dynamic rollover occupant containment test and a two sided static roof crush test which almost all cars then in production could not meet. By 1973, NHTSA implemented a static test in which almost all then in production cars could meet. In 1975, as part of the Minicars Research Safety Vehicle program contract, an epidemiological study based on projections ten years into the future, was conducted to identify performance test specifications for the vehicle and to identify compliance tests by which the vehicle should be evaluated. The goal was to demonstrate a major reduction in serious injuries and fatalities. The study identified 82 significant impact configurations for frontal, side, rear, and rollover crash modes. NHTSA then decided on a test and impact severity for each mode based on the frequency of serious injury and a 75% reduction in fatalities and serious injuries. The project was completed in 1980 with confirmed 50 mph (80 kph) frontal, 40 mph (64 kph) offset frontal, 40 mph (64 kph) side, 40 mph (64 kph) rear, and 30 mph (48 kph) rollover passive protection performance. However, it was not until 1990 that the 1970 FMVSS 208 frontal passive protection at 30 mph (48 kph) was fully implemented, and in 2002 for 30 mph (48 kph) side protection. The first lesson is that casualty reduction regulation cannot be politically justified unless the severity standard of the test is in the middle of what the industry is then producing or planning to produce. The second lesson is that such derived casualty reduction standards, when fully implemented, reduce fatalities by only about 20%. A third lesson might be that the Volvo XC-90, the outstanding performer in these JRS tests, after seven years of production has yet to be involved in even one fatal rollover.

DYNAMIC ROLLOVER EPIDEMIOLOGY

NHTSA – There are annually roughly 270,000 rollovers with 430,000 occupants. Rollovers account for 10,000 deaths (2.3% of rollover occupants), 5,000 from roof crush and 5,000 from ejection. There are 26,500 (6% of rollover occupants) serious to fatal injuries half outside and an equivalent number inside the vehicle. There are about 395,000 (91.7% of rollover occupants) not seriously injured.

Digges [1] 95% of rollovers and serious to fatal injuries result from two rolls or less.

Friedman [2] (1998 NASS file analysis) – There are comparatively few serious to fatal rollover data files in NASS. Analysis of the large number of not seriously injured data files indicated with high confidence that the average rollover roof crush was less than 4” (10.2 cm).

IIHS [3] Fatality and incapacitating injuries on average will reduce by about 25% for each unit increase of fleet roof strength to weight ratio (SWR). However, there are large injury rate variations from the average for vehicles with the same SWR as shown in Figure 1.

IIHS Statistically Based Ratings

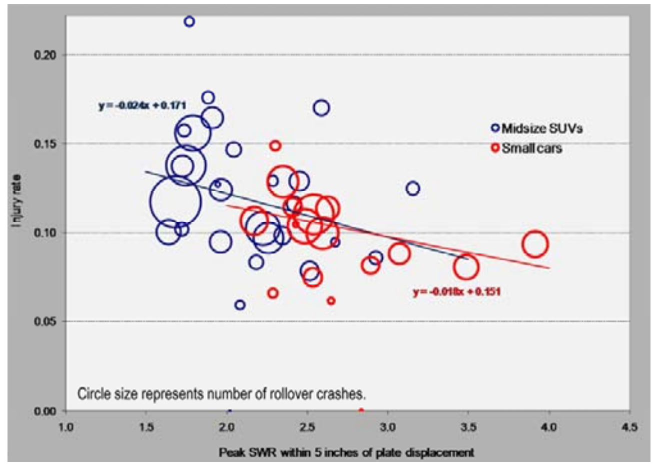

FIGURE 1. IIHS RELATIONSHIP OF INJURY RATES VS. SWR

Ridella [4] – Extremities account for roughly 2%, head injuries account for 11%, spine injuries account for 57%, and thoracic injuries account for 29.5% of the 26,500. Fatality Analysis Reporting System (FARS) fatalities are mostly from head and neck blunt force trauma and combinations of serious injuries.
Moffatt [5] (Malibu) – two roll, first roof impacts occur at a traveling speed of 20 mph to 22 mph (32 kph to 35 kph) and a roll rate of ~ 360°/sec.
Moffatt [6] Controlled Rollover Impact System (CRIS) Crown Victoria) – Very high Head Injury Criteria’s (HICs) occur to far side dummies at high roll rates (360°/sec) and sustained > 7 mph (11 kph) roof intrusion speeds.
Friedman (Hybrid III neck studies) – Pintar’s PMHS (Post-Mortem Human Subjects) hyperflexion injuries can be related to Hybrid III lower neck moment IARV’s (Injury Assessment Reference Values).
Friedman [7] (JRS) – Lower neck bending injuries occur to far side belted occupants with > 6” (15.2 cm) roof intrusion at > 7 mph (11 kph) intrusion speed.
Friedman [8] (JRS) High roll rates produce high intrusion speeds particularly in 10° pitch rollovers. The similarity of the general geometry and construction of vehicles relates residual and dynamic roof crush and with dynamic crush speed for each roll.
Nash [9] (Simulation and drop tests) relate impact speed to dummy injury measures.
Muzzy [10] – relates historical human and post-mortem human subjects test data to dummy head/neck musculature and injury.

A REAL WORLD DYNAMIC PROTOCOL

- Industry/Vehicle - In response to NHTSA’s 1995 implementation of FMVSS 201 and 214 and the offset frontal and side impact tests of IIHS, the strength of pillars and roof rails were substantially increased.

Because of impending Corporate Average Fuel Economy (CAFÉ) increases these improvements were implemented with high strength steel. As an incidental consequence, the SWR in the 216 test increased substantially. This is why there wasn't and isn't resistance to the 216 Final Rule or to IIHS' "best pick" SWR criteria of > 4.0.

- Friedman (M216) - NHTSA's evaluation of roof strength at 10º of pitch failed to recognize the 30% sequential reduction in strength on each side of the roof that has compromised the effectiveness of the final rule. Since industry will meet and exceed 216 for other design reasons there is no need for them to reinforce the windshield header to A-pillar / roof rail joint. A 2.5 lb. (1.13 kg) modification grossly improved a 2007 Camry's 10° pitch JRS test performance.
- Friedman (JRS research tests) – High roll rate, out of position dummy peripheral erection speeds reach 5 mph to 7 mph (8 kph to 11 kph), facilitating ejection and head/neck injury measures.
- Friedman – A sequence of rollover trajectory segments from loss of control to trip to roof impacts to rest has been hypothesized and analyzed. The serious to fatal injury potential analysis from each segment has been experimentally verified and identified the ballistic trajectory segments as the most injurious, from which a protocol was derived.

METHODS

Real world injury performance is thought to require a research simulation of the vehicle and occupant kinematics in the sequence of trajectory segments from the loss of control, to trip, to the ballistic trajectory, roof near and far side touch down, etc. through two rolls, to rest. There are variable parameters within each segment making it virtually impossible to characterize a single protocol. Fortunately a compliance test protocol should characterize the one most likely segment to result in serious injury and to differentiate the performance between vehicles in the current and future fleet.

The focus of 40 JRS production vehicle rollover tests has been on the ballistic segment, estimated by the investigation and analysis of over 400 real world rollovers and validated by experimentation, to result in the most serious head, neck, and spinal cord injuries and deaths. The forty tests were conducted with somewhat different protocols and normalized to a derived real world protocol.

NHTSA has statistically validated [11] a post crash negative headroom criteria five times more likely to be injurious [12] and Center for Disease Control (CDC) investigators have analyzed National Accident Sampling System (NASS) and Crash Injury Research and Engineering Network (CIREN) files to calculate the adjusted percent and odds of fatalities, head, neck, and spinal cord injuries, for ranges of residual roof crush [13]. These results have been merged to result in the injury risk assessment of the 40 JRS tests presented in the order of increasing residual crush and risk. The dummy injury measures could not be normalized among different protocols and were analyzed within a group of 15 tests conducted with similar protocols.

The results of comparisons between injury risk and SWR and between injury risk and dummy injury measures are plotted and discussed with attention to measurement details in the evaluation of anomalies.

RESULTS

The Relationship of Vehicle Injury Risk and Strength to Weight ratio (SWR)

Figure 2 illustrates the JRS measured residual roof crush of 40 JRS tests. This figure was derived from tests conducted at a number of different protocols and then normalizing the residual crush damage to a 21 mph (34 kph), 270º/sec and 10 º of pitch one roll protocol. Final ratings would be determined from conducting all tests at the same protocol but this normalization demonstrates the expected results. The Centers for Disease Control and Prevention (CDC) contactors calculated (from NASS and CIREN data files) the percent of fatalities and injuries and the odds ratio [13] which has been overlaid on the corresponding bands of residual roof crush. CDC confirms the author's 1998 SAE paper [14] that 3.86" (9.8 cm) of residual roof crush would eliminate most belted serious injuries in rollovers.

The basic normalization procedure was checked as indicated by the vehicles denoted with an "*"; two separate tests of the same model year vehicles, one of which was tested at 15 mph (24 kph), 5° of pitch and 190°/sec roll rate and normalized to the other test which was conducted at the 21 mph (34 kph), 10° of pitch and 270°/sec roll rate. The error is about 5%. The dynamic JRS tests therefore have the ability to distinguish a reasonably safe vehicle by NHTSA's own injury risk criteria.

A compliance test could also be based on subtracting the original headroom from the measured roof crush results of a specified JRS test. The headroom (and a variety of other injury related parameters) for a 50th percentile male Hybrid III dummy in each of these vehicles has been measured as shown in Table 1. Figure 3 incorporates those headroom results and puts the residual crush chart (Figure 2) into the perspective of NHTSA's Post Crash Headroom (positive or negative) allowing a comparison to the FMVSS 216 requirement of an SWR of >3 tested on both sides and in sequence. Measured values of non-injurious Post Crash Positive Headroom (PCPH) are shown below the "0" line for clarity. Post Crash Negative Headroom (PCNH) results, which is five times more likely to be injurious, are shown above the "0" line. A concern here is that a vehicle like the Toyota Scion xB, which complies with the standard (an SWR= 6.8) but has PCNH, would be 5 times more likely to be injurious. On the other hand, the Honda CR-V does not comply with the standard but has PCPH and is not injurious. This means that some other factors beside roof strength are influencing the outcome. Factors like vehicle kinematics, roof buckles, geometry, elasticity, and the consequential dynamic intrusion and intrusion speed can be measured by the occupant (dummy) injury results to determine their affect.

TABLE 1. PARAMETERS RELATED TO DUMMY INJURY MEASURES

Vehicle	Headroom Measurement (inches)	Max. Lap Belt Load Roll 1 (lbs)	Max. Shoulder Belt Load Roll 1 (lbs)	Max. Lap Belt Load Roll 2 (lbs)	Max. Shoulder Belt Load Roll 2 (lbs)	Impact Angle, Roll Rate Roll 1	Impact Angle, Roll Rate Roll 2	Far Side Road Load Roll 1 (lbs)	Far Side Road Load Roll 2 (lbs)
2005 Volvo XC90	6.25	215	101	119	124	143º, 179º/sec	139º, 180º/sec	18,229	22.145
2007 VW Jetta	4.25	164	105	106	115	142º, 156/sec	143º, 172º/sec	17,362	20,798
2007 Toyota Camry	5	115	100	224	94	141º, 138º/sec	140º, 170º/sec	19,242	25,038
2007 Honda CR-V	4.25	123	102	126	119	143º, 196º/sec	141º, 209º/sec	16,115	14,264
2009 Nissan Versa	5	237	175	225	222	144º, 187º/sec	145º, 194º/sec	19,451	19,151
2006 Hyundai Sonata	4.5	127	93	200	190	143º, 133º/sec	145º, 166º/sec	17,711	31,380
2007 Toyota Camry (Hybrid)	5	177	136	154	123	143º, 180º/sec	136º, 185º/sec	20,024	28,919
2008 Scion xB	6.5	432	207	206	94	141º, 201º/sec	146º, 196º/sec	27,861	20,422
1998 Ford Explorer	3.75	104	69	62	7	146º, 183º/sec	143º, 186º/sec	15,964	25,624
2006 Pontiac G6	2.5	171	128	324	147	139º 172º/sec	140º, 175º/sec	19,062	33,406
2006 Honda Ridgeline	4.75	123	79	166	81	145º, 208º/sec	145º, 203º/sec	20,385	33,023
2006 Chrysler 300	4.5	137	101	539	127	146º, 161º/sec	147º, 156º/sec	24,001	43,085
2007 Chevrolet Tahoe	5.25	192	140	244	64	142º, 213º/sec	143º, 210º/sec	24,727	39,575
2007 Pontiac G6	4.75	87	92	N/A	N/A	142º, 172º/sec	N/A	19,185	N/A
2007 Jeep Grand Cherokee	3.5	125	91	30	10	147º, 197º/sec	149º, 190º/sec	23,908	32,293

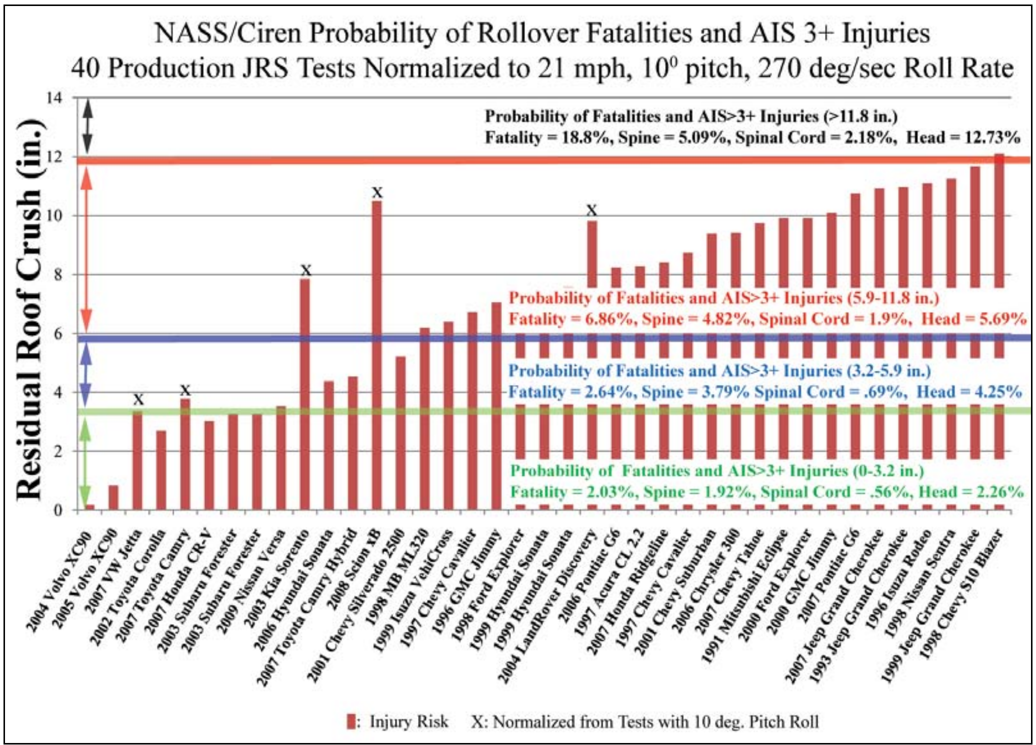

FIGURE 2. ORDERED INJURY RISK (BY NORMALIZED RESIDUAL CRUSH) OF 40 PRODUCTION VEHICLES

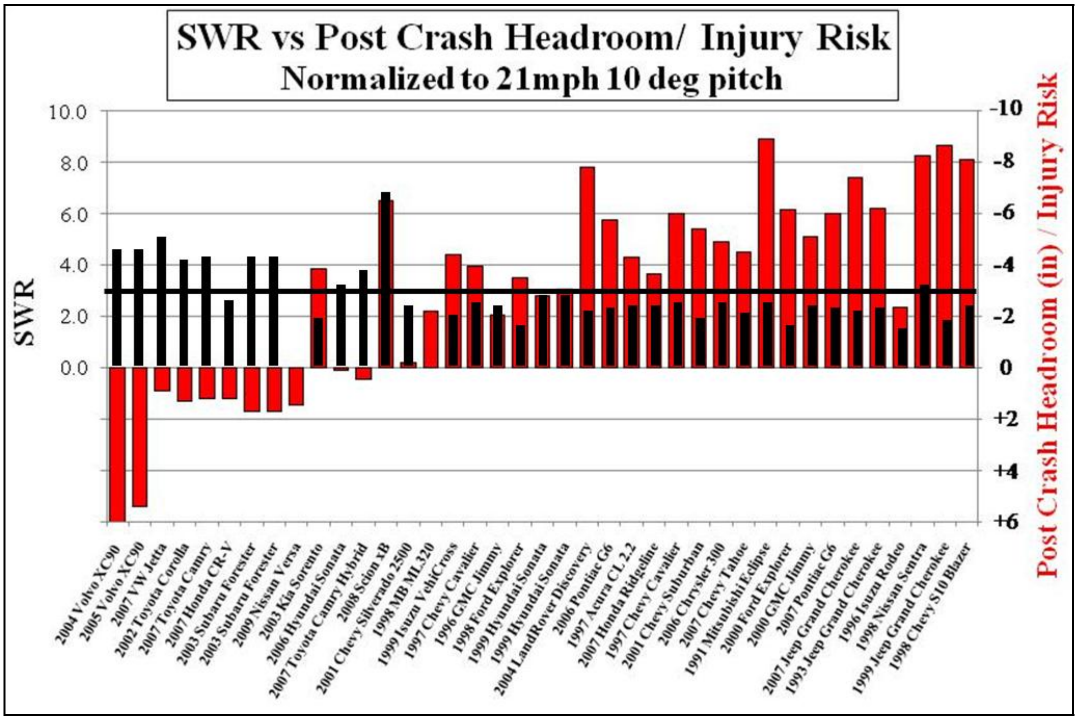

FIGURE 3. ROOF SWR OVERLAID ON ORDERED INJURY RISK FOR 40 PRODUCTION VEHICLES

The Relationship of Vehicle Roof Crush (Injury Risk) and Dummy Injury Measures

The variation in the 40 vehicle test protocols affected and precluded normalization of the dummy injury measures. However, 15 of those vehicles were tested with belted dummies to essentially the same low severity protocol. The dummy neck bending injury measure My (based on a percent of Injury Assessment Reference Value [IARV]), is shown in Figures 4 and 5 with the actual (non-normalized) residual roof crush bar for each roll. The neck to torso angle in the first roll was at 7º except for the first Pontiac G6, where it was 30º. For the second roll, the neck to torso angle was 30º. Although excursion in the belts and dummy position at impact varied (as it would in the real world), generally speaking, the bending injury measure is consistent with roof crush. The previously mentioned non-linearity of open section structure, panel buckling and occupant position at impact as seen in the videos account for some of the anomalies in the Pontiac G6 vehicles. Another is the 2" difference in headroom and other injury measure related factors as shown in Figure 5.

On the other hand the compressive Fz, IARV itself is grossly contradicted when considering the dummy Fz, IARV injury measure performance criteria shown in Figure 6. Clearly the Fz, IARV is not a representative compressive injury measure at 4,000 N. Much discussion in the Biomechanical community has focused on this anomaly and suggest that based on PMHS data a fall height of 1.5 m (about 5'), corresponding to about 12.5 mph (18.5 kph) impact speed was required for head injuries. In dummy drops, such a height and speed corresponds to a neck force of about 12,500 N or 3 times the current IARV. None of the compressive loads would have exceeded that adjusted criteria with the low severity protocol. In dummy vehicle rollover roof impacts, such a height and speed correspond to a neck force of about 10,000 N.

Our studies [15] have shown that IARVs based on peak values are at best an empirical relationship to injury and are unreliable as shown in Figure 6. The most reliable indicator of head and neck injury takes into account the momentum exchange with the roof which is the true measure of injury potential at the dummy's head as measured by the dummy instrumentation. The Integrated Bending Moment (IBM) directly integrates the resultant bending moments of the lower neck over the duration of time over which it is bending. These low severity IBM test results are plotted in Figure 7 and 8. These results more clearly identify the anomalies between the CR-V with an SWR of 2.6 and the Ridgeline with an SWR of 2.4. Similarly, the substantially higher IBM values at 10º of pitch in Roll 2 for some vehicles and not others are significant. In comparison with bending moments IARV criteria, an IBM of 13 has been proposed.

DISCUSSION

General Observations

Comparing the two tests of the Pontiac G6 indicates as was demonstrated in Figure 2 that the roof intrusion of a weak roof is non-linear and the injury measure results are related to the roof intrusion with the same belt system and different headroom values.

Several comparative observations can be drawn from the data of Figures 4 and 5 and 5" (12.7 cm) spite of the variability of belt performance and half the impact momentum compared to the proposed real world protocol.

Many argue that the Hybrid III dummy is not biofidelic in rollovers and therefore results are misleading. Our studies show an intentional and comparable lack of biofidelity in frontal and side impact test crashes. This stems from the unrealistically strong muscularity of the dummy's neck (modeled after a young military man's fully tensed neck) [16]. However, the performance in a compliance test is comparative and while there is no consensus of biomechanics on the dummy, IARV criteria for frontal, side, and rollover tests, we continue to use the existing peak values. The correct approach (and the one we have taken) is to adjust the dummy musculature to more typical levels and recalibrate it to the existing IARV and cadaver data as shown in Table 2.

TABLE 2. LOWER NECK IARV'S FOR 10% PROBABILITY OF AN AIS≥3 INJURY

Neck Type	My (Nm) Flexion	My (Nm) Extension	Mx (Nm)	Axial Fz (N)
Production	380	−156	268	4000
Low Durometer	90-110	−38-−46	59-90	1640-2000
Human/Cadaver	58			1500

The results such as seen in these 15 tests then will suggest how to match the criteria to the frequency of human head neck injury.

Although many dynamic vehicle test parameters and dummy injury measures were collected as shown in Annex A for Roll 2 of the 2008 Scion xB in Table 3 and Roll 2 of the 2007 Honda CR-V in Table 4, normalization to the real world protocol was not practical.

However, Figures 4 and 5 are the actual (not normalized) residual roof crush ordered protocol results overlaid with comparative lower neck peak flexion moment, My. Injury measures collected in each roll of a two roll low severity (15 mph [24 kph], 190°/sec) protocol are shown as a percentage of IARV.

Although none of the compressive forces were high enough for a head injury in the low severity protocol, head injuries are a significant cause of death. In these low severity dynamic tests we measured roof intrusion speeds of 12 mph (19 kph), but not at the dummy's head. Only one test was conducted with the derived real world protocol but with an in-position dummy. The 1999 Sonata with an SWR of 2.8 intruded at the A-pillar at 12 mph (19 kph). An out of position dummy moves towards the roof at 5 mph to 7 mph (8 kph to 11 kph) for an impact closing speed of 17 mph to 19 mph (27 kph to 31 kph), fast enough for a head injury.

Detailed Investigation of Anomalies

The two JRS tests that were significantly injury risk and injury neck bending measure anomalies to their static SWR measurements were investigated. IIHS quasi static roof strength tests were analyzed and used to determine vehicle SWRs. The Scion has an SWR of 6.84 (peak load was 21,041 lbs = 93,595 N) and CR-V has SWR of 2.6 (peak load was 8,686 lbs = 38,637 N).

The 2007 Honda CR-V performed far better than average for its SWR and the 2008 Scion xB performed much worse than average for its SWR in the JRS dynamic tests than their static SWR would predict. Both performed well in the first 5º pitch test (Scion better than CR-V) while the Scion was much worse and one of the worst performers overall in the 10º of pitch test.

Both were tested at approximately 15 mph (22 kph), with 5º and then 10º pitch, at a roll rate of 180º/sec. The headroom in the Scion was about twice the headroom in the CR-V. Because of the vehicle's geometry, the A-pillar radius to the CG in the Scion was 15% greater than the CR-V, the roll moment of inertia and the peripheral impact velocity to the roadbed of the Scion for the same roll rate was of considerably higher severity.

This is the same effect as the comparison of the Honda CR-V and the Honda Ridgeline. In addition, the structural integrity of the CR-V roof was enhanced (from the previous model run) by the addition of a high strength contoured sheet metal panel glued to the underside of the roof panel and attached to the roof rail.

The CR-V was probably designed like the XC-90 to handle rollover road loads elastically and particularly rolls at 10º of pitch while the Scion was probably designed to structurally protect occupants in frontal, frontal offset, and side impacts with consequential but incidental roof strength.

The geometry effect of the Scion is also shown by the road load in Roll 2 as indicated in Table 1. The Scion is the only vehicle whose road load in Roll 2 is substantially less than in Roll 1. Decreased road load and increased intrusion results when only the roof is involved.

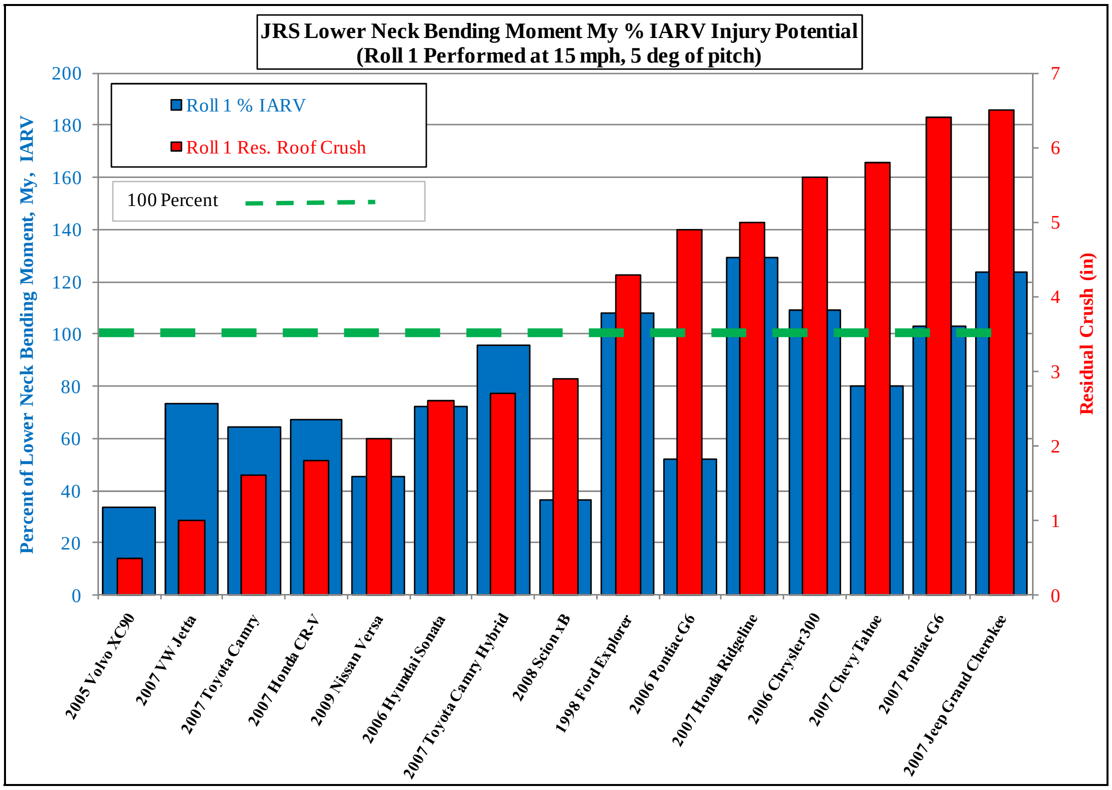

FIGURE 4. INJURY RISK AND %IARV BENDING MOMENT MEASURES FOR 15 VEHICLES (ROLL 1)

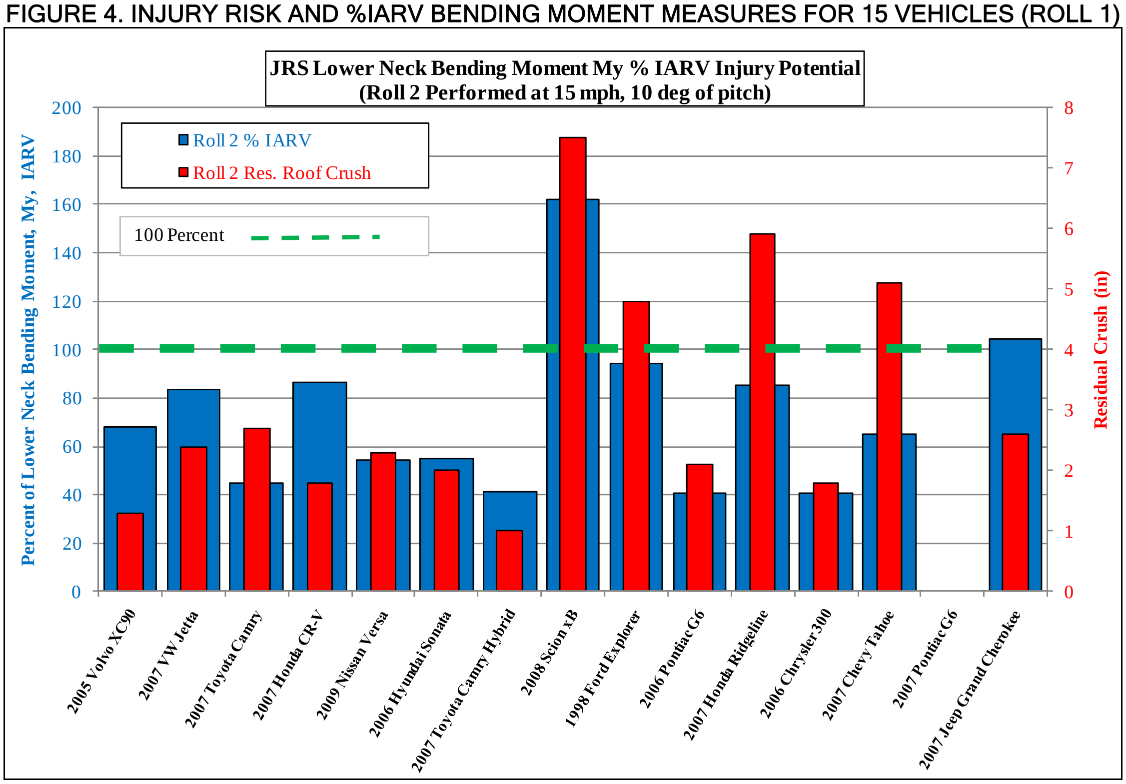

FIGURE 5. INJURY RISK AND %IARV BENDING MOMENT MEASURES FOR 15 VEHICLES (ROLL 2)

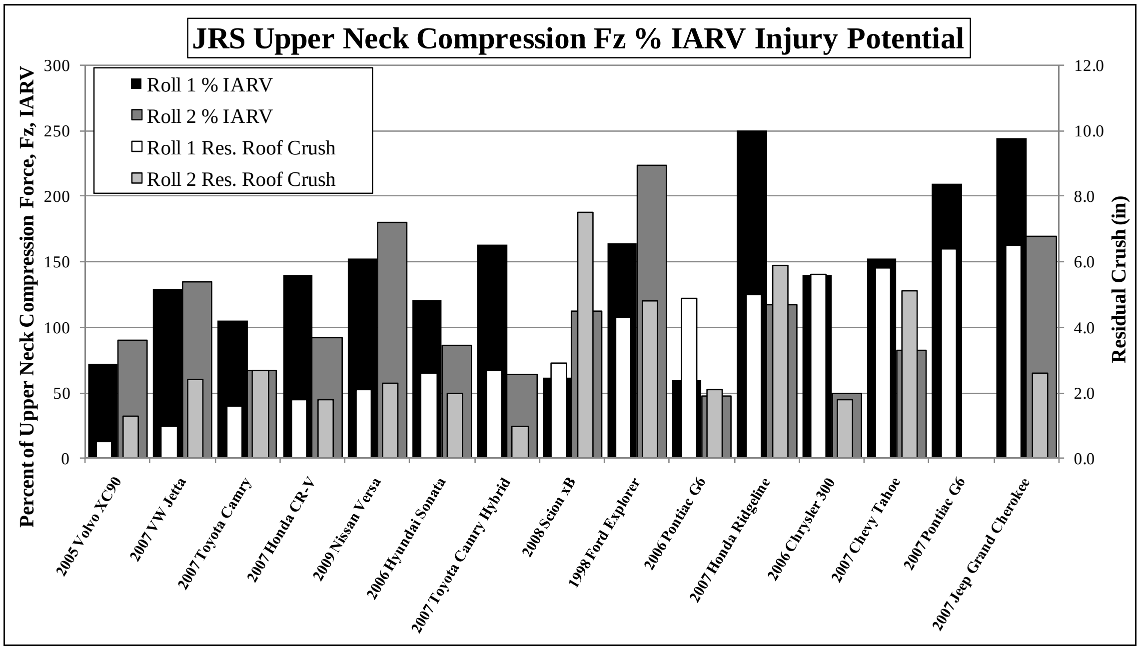

FIGURE 6. ORDERED INJURY RISK AND %IARV Fz COMPRESSION FORCE MEASURES

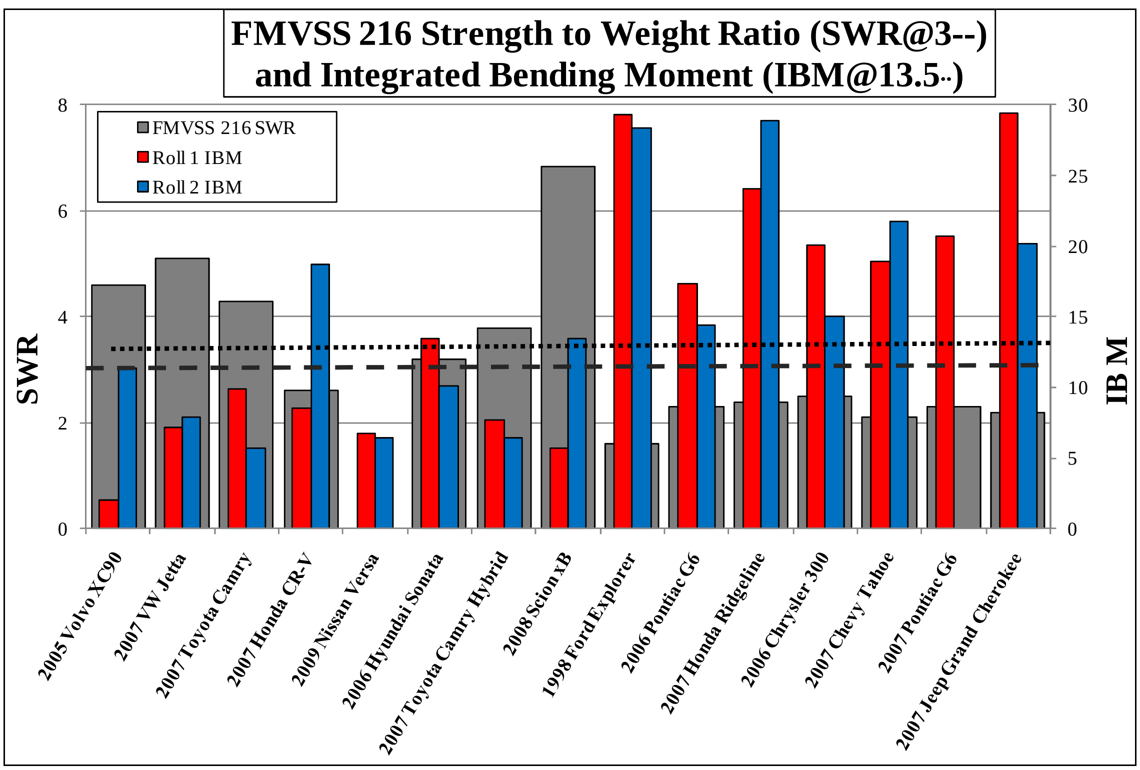

FIGURE 7. FMVSS 216 SWR AND IBM

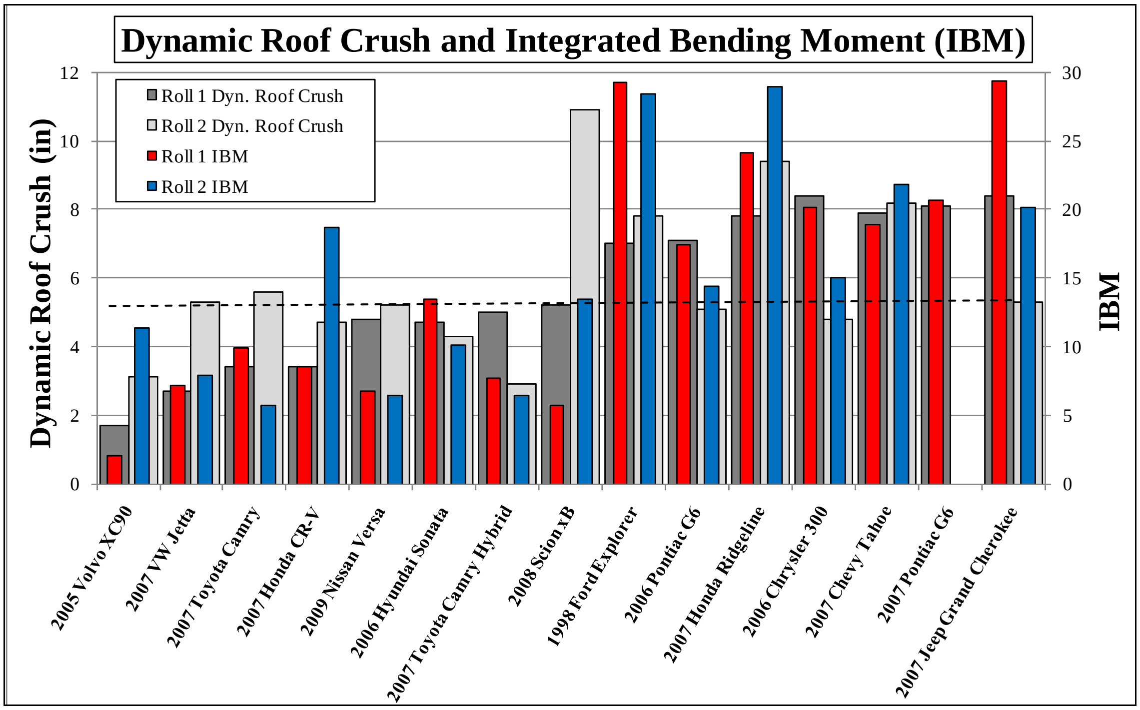

FIGURE 8. DYNAMIC ROOF CRUSH AND IBM

CONCLUSIONS

On average the strength to weight ratio (SWR) of each vehicle is representative of injury risk but dummy injury measure performance from individual vehicle design differences; result in dynamic performance anomalies greater than the average potential improvement of injury rate. This is characteristic of the diversity of vehicle injury rate performance at similar SWR as shown by IIHS statistical analysis.

Vehicle injury potential performance in a dynamic rollover should be the result of dummy injury measure criteria which take into account the dummy kinematics and position at impact, belt and other safety system effectiveness and the dummy's interaction with the vehicle structure. Although useful comparisons can be made with the low severity protocol and existing peak value Injury Assessment Reference Values (IARVs), as illustrated here for neck bending, real world severity tests with FMVSS 216 compliant vehicles, and a momentum function such as the integrated bending moment (IBM) would be more reliable.

A pilot test series using the proposed real world protocol will provide data to sort the respective and combined effects of roof intrusion and speed, vehicle geometry, road load, dummy head/neck/spine and thorax injury measures, belt, and other safety system performance.

Static test compliance criteria do not specify the injury measure performance required to reduce the number and severity of serious to fatal injuries.

A pilot rollover test program with two or three vehicles of each type (small, mid-size, large cars; small pickups; and small and mid-size SUVs) utilizing the derived real world severity protocol is needed to confirm the normalized injury risk and comparative head/neck/spine injury measure test results of vehicle roof structure and occupant protection system features.

The Jordan Rollover System (JRS) meets the requirements for a dynamic compliance test, equivalent to those of frontal and side impacts.

The JRS has the potential to both evaluate and validate the Finite Element Model performance of the structural model with which the vehicle was designed. It also has the ability to assist in developing and evaluating the performance of a vehicle's occupant protection features in all variations of rollover kinematics and with occupants of all sizes.

LIMITATIONS

The 40 JRS tested production vehicles were conducted with four somewhat different protocols. A reasonable basis for normalization to a separately developed real world protocol was derived and applied for the injury risk chart. Fifteen of the tests that were conducted to similar low severity protocols were used to compare dummy injury measures. The anomalies are discussed with measured and IARV referenced data.

ACKNOWLEDGMENTS.

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Annex A

JRS LOW SEVERITY ROLL 2 DATA of the 2008 TOYOTA SCION xB and 2007 HONDA CR-V

Table 3 of Roll 2 of the Toyota Scion xB with Low durometer Neck

Roll 2 – 02/12/2010

Summary of Results

Instrument	Peak Value	Residual Intrusion (inches)	Peak Velocity (mph)
Sum of Vertical Load Cells (near side contact)	3,283 lbs		
Sum of Vertical Load Cells (far side contact)	20,422 lbs		
Sum of Lateral Load Cells (near side contact)	664 lbs		
Sum of Lateral Load Cells (far side contact)	2,392 lbs		
Driver's Side A-Pillar String Potentiometer	10.9 in	7.5	13.0
Driver's Side B-Pillar String Potentiometer	4.6 in	2.7	5.8
Roof Header String Potentiometer*	13.5	10.0	13.7
Passenger's Side A-Pillar String Potentiometer	0.1 in	-0.2	1.4

*String Pot value measured by video analysis

Instrument	Maximum Value	Minimum Value
Lab Belt Load	206 lbs	-2 lbs
Shoulder Belt Load	94 lbs	-1 lbs
Dummy Head Acceleration Ax	44 g	-21 g
Dummy Head Acceleration Ay	28 g	-9 g
Dummy Head Acceleration Az	18 g	-5 g
Lower Neck Load Cell Fx	863 N	-302 N
Lower Neck Load Cell Fy	211 N	-542 N
Lower Neck Load Cell Fz	70 N	-937 N
Lower Neck Load Cell Mx	8 N-m	-29 N-m
Lower Neck Load Cell My	146 N-m	-18 N-m
Upper Neck Load Cell Fz	127 N	-1,842 N

Table 4 of Roll 2 of the 2007 Honda CR-V with Production Neck

Roll 2 – 12/18/2008

Summary of Results

Instrument	Peak Value	Residual Intrusion (inches)	Peak Velocity (mph)
Sum of Vertical Load Cells (near side)	11,128 lbs		
Sum of Vertical Load Cells (far side)	14,264 lbs		
Sum of Lateral Load Cells (near side)	879 lbs		
Sum of Lateral Load Cells (far side)	1,659 lbs		
Driver's Side A-Pillar String Potentiometer	4.7 in	1.8	5.3
Driver's Side B-Pillar String Potentiometer	2.6 in	0.6	3.4
Roof Header String Potentiometer	4.8 in	1.3	5.4
Passenger's Side A-Pillar String Potentiometer	2.0 in	0.6	2.4

Instrument	Maximum Value	Minimum Value
Lower Neck Load Cell, Fx	927 N	-170 N
Lower Neck Load Cell, Fy	26 N	-843 N
Lower Neck Load Cell, Fz	171 N	-3,496 N
Lower Neck Load Cell, Mx	8 N m	-107 N m
Lower Neck Load Cell, My	328 N m	-34 N m
Upper Neck Load Cell, Fz	133 N	-3,687 N
Upper Neck Load Cell, Mx	90 N m	-28 N m
Upper Neck Load Cell, My	18 N m	-103 N m
Upper Neck Injury Criteria*	1.30	0
Lower Neck Injury Criteria**	1.10	0
Belt Load Cell - lap	126 lbs	0 lbs
Belt Load Cell - torso	119 lbs	0 lbs

*Based on injury measures presented in Mertz, et. al., 2003.
**Based on injury measures presented by NHTSA.