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March 27, 2008

The Honorable Nicole Nason, Administrator
National Highway Traffic Safety Administration (NHTSA)
1200 New Jersey Avenue SE
Washington DC 20590

Re: Docket No. NHTSA-2008-0015

Dear Ms. Nason:

The only benefit of the National Highway Traffic Safety Administration's delay in completing rulemaking on rollover occupant protection is that we now have definitive, scientific data that show the specific benefits of various vehicle performance levels for improving that protection. We also have good information about the benefits and shortcomings of various tests for rollover occupant protection. If you take advantage of this information, your decisions on rulemaking and consumer information addressing rollover occupant protection questions can save many thousands of serious to fatal injuries that could result from rollover crashes.

Rollover Occupant Injury is Definitely a Function of Roof Crush

Crash data analyses by NHTSA and the Insurance Institute for Highway Safety have found a strong, statistically significant relationship between roof crush resistance and rollover survivability using various accident data files. In addition, NHTSA has shown that if roof crush exceeds the point where the roof would contact a typical occupant's head, the probability of occupant injury increases substantially.

Hugh DeHaven set forth the proposition that occupant compartment integrity – both resistance to intrusion and containment of the occupant – were a critical part of occupant crash protection in all crash modes.[1] NHTSA accepted this principle more than 35 years ago in its rulemaking on roof crush resistance and ejection,[2] respectively, and it has not retreated from this principle.

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[1] DeHaven, Hugh, "Accident Survival – Airplane and Passenger Automobile," A paper presented at the Annual Meeting of the Society of Automotive Engineers, January 1952. This paper was reprinted in William Haddon, Jr., M.D., Edward A. Suchman, and David Kline, *Accident Research Methods and Approaches,* Harper and Row, New York: 1964,

[2] Docket #2-6, 32 FR 14281 (Oct. 14, 1967); Docket #2-8, 32 FR 14281 (Oct. 14, 1967), Docket #2-6, 36 FR No. 3 (Jan. 6, 1971). Docket "1999-5572, 66 FR 53376 (Oct. 22, 2001), Docket #2005-22143, 70 FR 49223 (Aug. 23, 2005), Docket #2008-0015, 73 FR 5484 (Feb. 1, 2008).~~Docket #2-6, Docket #2-8, 32 FR 14281 (Oct. 14, 1967).~~

We are concerned that NHTSA has unnecessarily and improperly limited the information and factors to be considered in its roof crush rulemaking in several ways.

Ejection is a Strong Function of Roof Crush

First, NHTSA has refused to acknowledge that greater roof crush resistance can reduce casualties among people who are not wearing safety belts (including those who are fully ejected). There are two respects in which occupants who are not belted should be included as potential beneficiaries of roof crush resistance rulemaking:

- A strong roof can protect side windows, reducing the potential for ejection, and
- In keeping with NHTSA's programs to increase safety belt use, some who would be ejected at today's belt use rates might be contained in the future and must be counted among the benefits of a stronger roof.

NHTSA must respond to the Congressional mandate to address the problem of occupant ejection with a final rule by October 1, 2009. There are two principal factors that facilitate occupant ejection: failure to use the available safety belts, and failure of the tempered side glazing. It is clear that:

- Increased safety belt use will proportionally increase the number of beneficiaries of a stronger roof, and
- Control of side window failure will, at minimum; require that side window frames not be significantly distorted during roof impacts that are typical of rollovers; which can only occur if the roof retains its basic structural integrity.
- .

Failure to establish a sufficiently stringent roof crush requirement in this rulemaking will sabotage NHTSA's effort to control ejection.

Jordan Rollover System Test Results

The Center for Auto Safety has received two generous grants from the Santos Family Foundation for two Jordan Rollover System (JRS) test programs. The first was to demonstrate the repeatability and reliability of the JRS. In the first phase, three essentially identical vehicles were tested on the JRS with and without anthropometric test dummies to determine the degree of repeatability of the system and test results. These tests demonstrated that the tolerances of the test parameters can be very closely controlled, that the crush of the vehicle roofs was highly consistent, and that readings from dummies included in the second test of each vehicle were also within close limits. In the second phase, a number of recent model passenger cars and SUVs that were provided by the State Farm Auto Insurance Company are being tested to determine the dynamic rollover occupant protection capability of some representative contemporary vehicles and to compare the dynamic test results to NHTSA's quasi-static FMVSS 216 test results.

Repeatabilityof the JRS: the Subaru Forester Tests

In the recent repeatability series, we tested three 2003-2004 Subaru Foresters that were essentially identical in body style and equipment. All three were used vehicles and one had modest frontal crash damage that had been repaired but that did not involve the vehicle from the firewall and A posts back. None of the cars had sun roofs and all had roof racks. All had four cylinder engines with automatic transmissions and weighed 3,237 lbs, 3,253 lbs and 3,250 lbs, respectively, as tested. Two tests of each vehicle were conducted: the first without dummies but with complete instrumentation, the second with a fully instrumented Hybrid III dummy restrained in the driver (initially trailing) seat.

First JRS Test Series. The first test of each Forester was conducted with a road speed of 18 mph, a vehicle roll rate of 240°/sec., 10 degrees pitch and yaw, and a 4" drop height to the leading side of the roof.[3] Photographs of the three vehicles following the first tests are shown in Figure 1. Traces of the road load in the three first tests are shown in Figure 2.

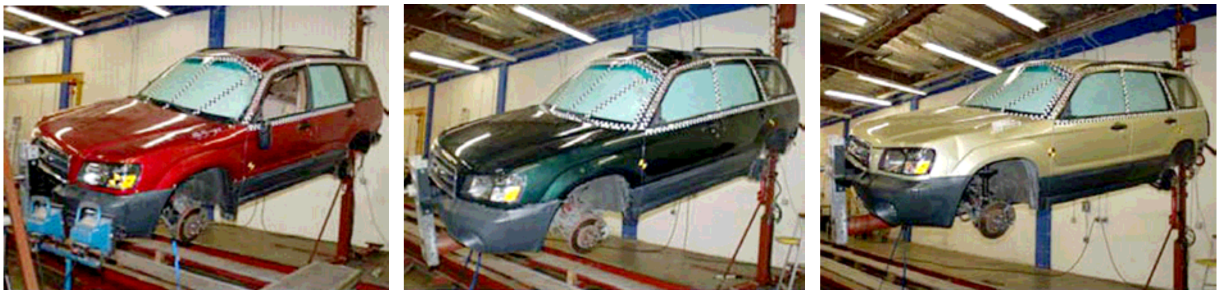

Figure 1. Photographs of the three Subaru Foresters following the first test on the JRS.

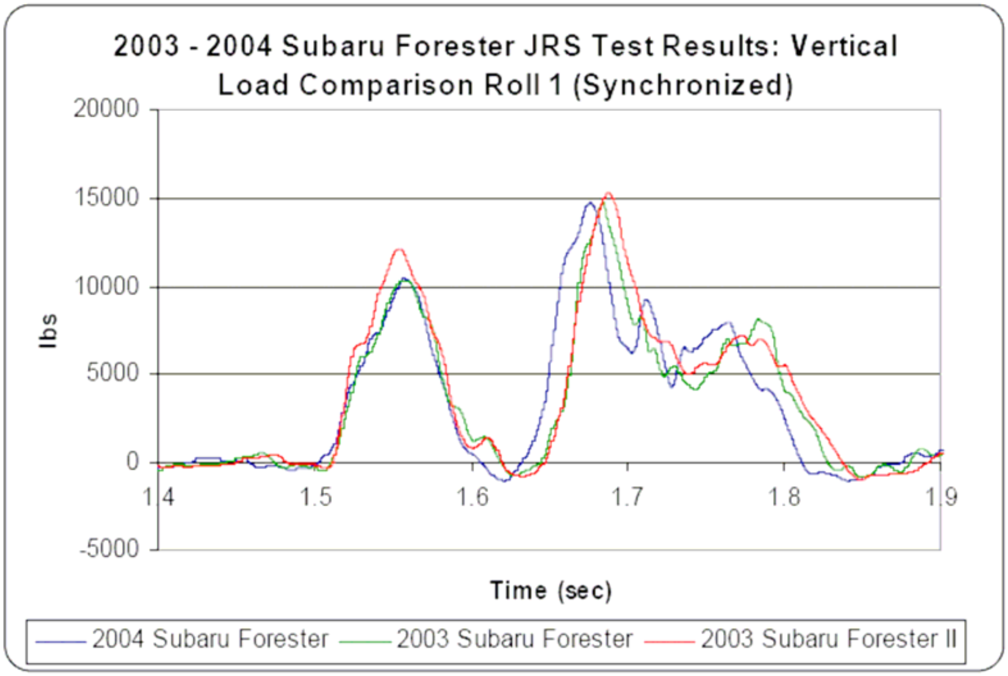

Figure 2. Comparison of roof to road force loads in three initial tests of Subaru Foresters using the JRS.

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[3] The drop height of the JRS is established by manually rotating the vehicle above the road surface to find the part of the roof that is furthest from the longitudinal rotation axis: typically the roof near the top of the A pillar, but sometimes the roof rack. The initial height of the vehicle is adjusted to put this point 4 inches above the road surface to establish the drop height. In the actual test, this point may not be directly under the roll axis which accounts for the variation in drop heights particularly in the second test run after the vehicle has been damaged.

The Foresters performed fairly well in these tests. The B pillar is exceptionally strong, acting as a roll bar for this vehicle. By contrast, the A pillar and windshield header displayed weakness with buckles forming in the windshield header several inches inboard of the top of the A pillar and further toward the middle. That is reflected in the major A pillar, but minimal B pillar crush. The B pillar strength limited the A pillar intrusion. The crush at the front of the roof resulted in some distortion of the roof panel. All three vehicles showed similar patterns of roof damage.

We use string potentiometers inside the vehicle to measure roof intrusion at key points in the roof area.[4] The maximum dynamic roof crush and residual crush are shown in Figure 3. The standard deviation of the maximum dynamic crush at the A pillar was 0.31 inches and the standard deviation was only 7 percent of the average and only 6 percent of the generally accepted maximum acceptable roof crush (5 inches in the FMVSS 216 test).

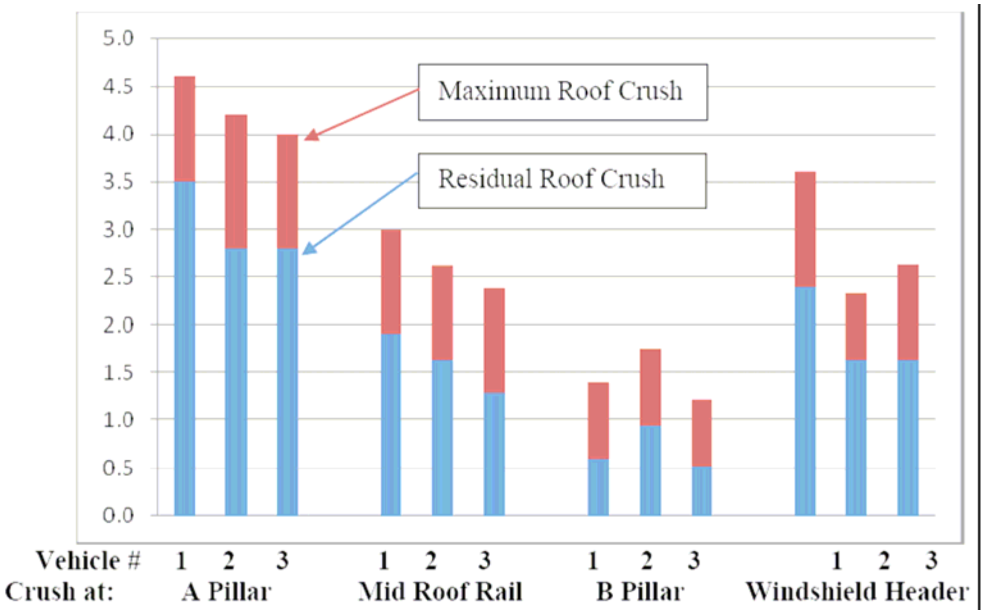

Figure 3. Maximum and residual roof crush, in inches, following the first test of the three Subaru Foresters.

Roof intrusion speed, shown in Figure 4, provides a better measure than gross intrusion of the potential for head or neck injury. Again, the A pillar crush speed is more than twice that of the B pillar. The standard deviation of the maximum dynamic crush at the A pillar was 0.41 ft/sec and the standard deviation was only 5 percent of the average.

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[4] String potentiometers are placed at: (a) the top of the driver A pillar, (b) mid-way between the driver A and B pillars, (c) at the top of the driver B pillar, (d) at the roof header on the driver's side, (e) directly above the driver's head in a normal seating position, (f) inboard of the driver B pillar, (g) the top of the passenger side A pillar, and (h) the top of the passenger side B pillar.

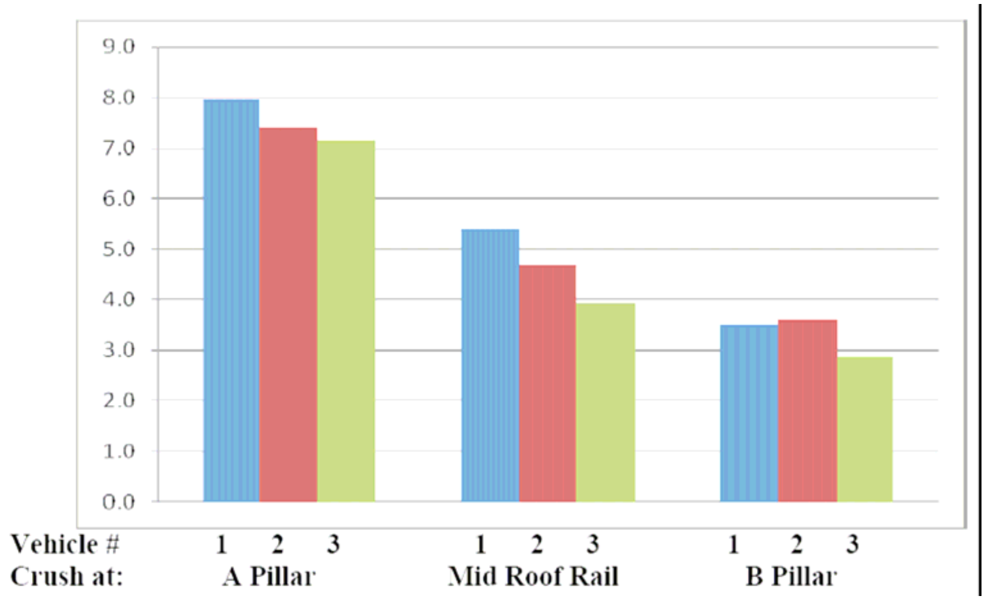

Figure 4. Maximum roof intrusion speed, in ft/sec, in the first test of the three Subaru Foresters.

Second JRS Test Series with Dummies. The second test of each of the three Foresters was conducted with an instrumented Hybrid III 50th percentile dummy restrained by the available lap/shoulder belt in the driver position (the initially trailing side in these tests where maximum roof crush generally occurs). The dummies were positioned according to the procedures set forth in FMVSS 208 at the mid seating position, but no additional restraints were placed on the dummy to constrain it during the test. In these tests, the road speed was 12 mph, the vehicle roll rate was 170°/sec., the vehicle was at 10 degrees of pitch and yaw, and was dropped from 4” to the initially leading (passenger) side of the roof.

Photographs of the three vehicles following the second tests are shown in Figure 5.

Figure 5. Photographs of the three Foresters following the second JRS tests.

Traces of the road loads in the three second roll tests are shown in Figure 6. The roof to road force loads show more variations than the first test results after 2.15 seconds, probably due to detailed difference in the vehicles following the first test.

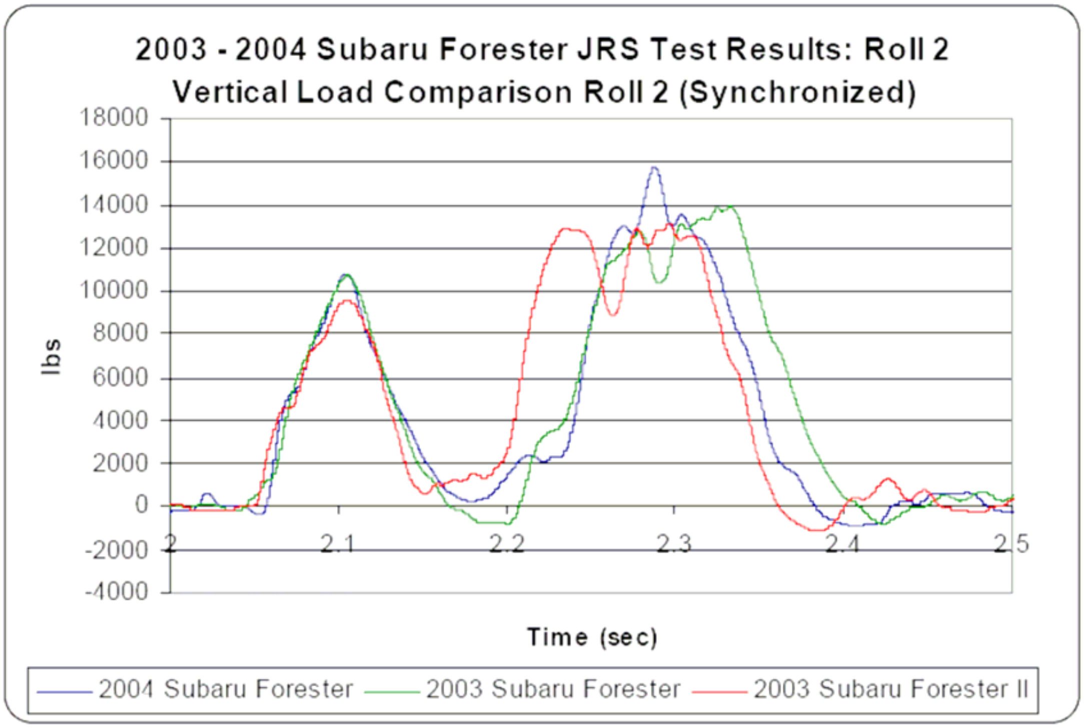

Figure 6. Comparison of roof to road force loads in three subsequent tests of Subaru Foresters (vehicles already damaged in first JRS test) with dummies using the JRS.

Because of the strength of the B pillar and the fact that the dummy remained well behind the A pillar, it registered relatively low head acceleration and neck loads that would be considered survivable without serious injury. Had the head been further forward, under the front corner of the roof, the intrusion rate would have been near the threshold – an intrusion speed of approximately 10 ft/sec (3 m/sec) – to produce a serious cervical spine injury.

Figures 7 and 8 show the intrusion and intrusion rates in the second series. The standard deviation for maximum roof crush at the A pillar divided by the average is 11%.

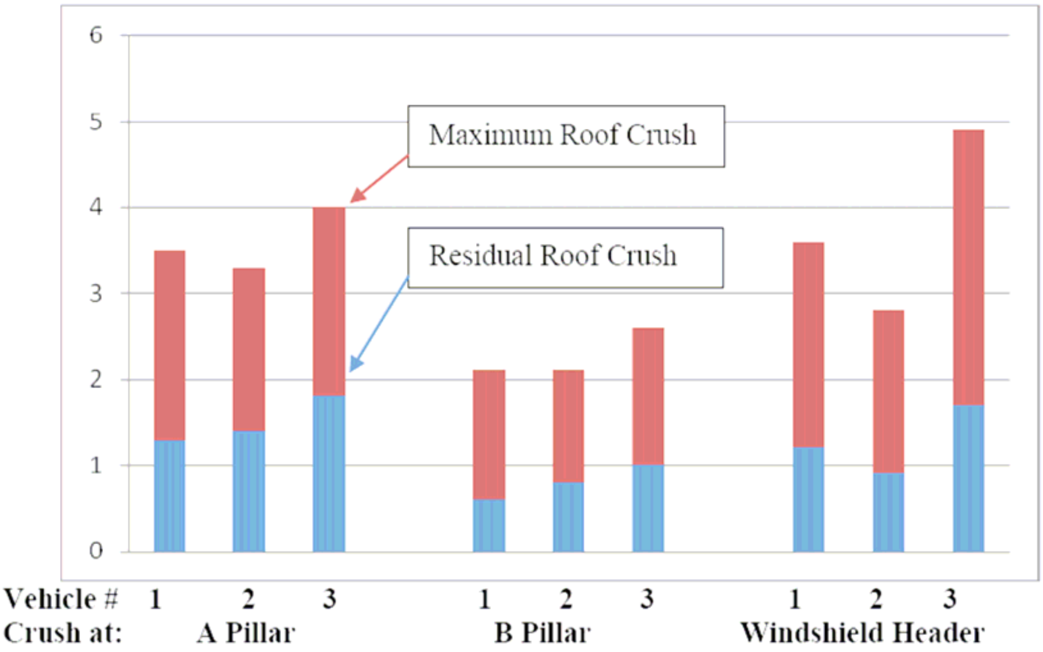

Figure 7. Maximum and residual intrusion roof crush, in inches, following the second test of the three Subaru Foresters. (Because of the presence of the dummy, no measurement could be taken from the midpoint of the roof rail. }

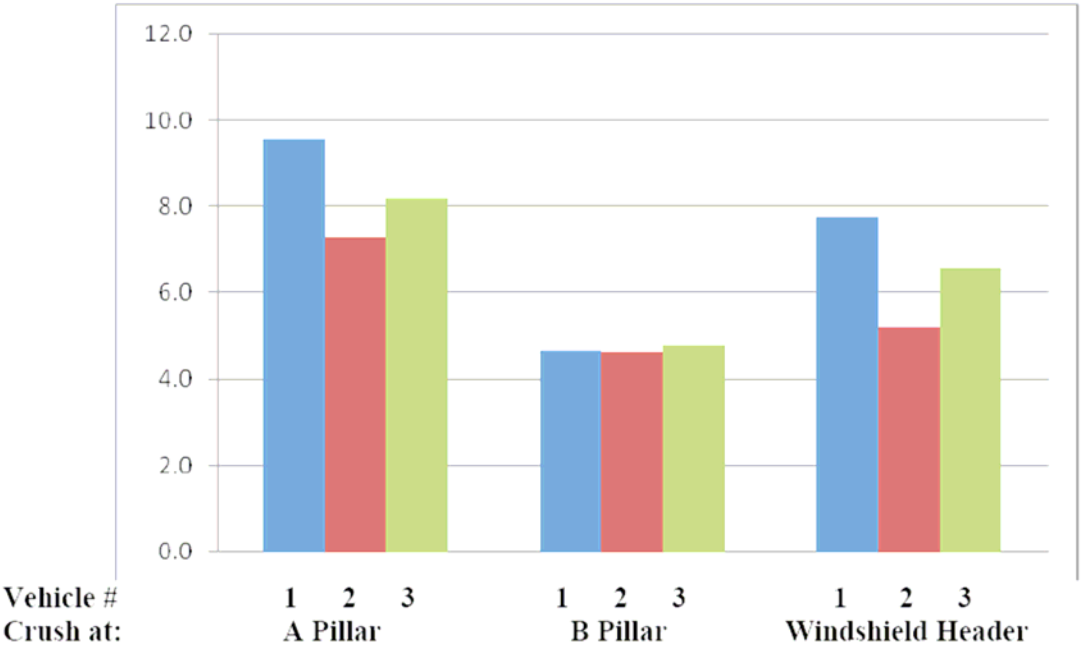

Figure 8. Maximum roof intrusion speed, in ft/sec, in the second test of the three Subaru Foresters.

Dummy head acceleration and maximum neck force results showed that the standard deviation divided by the average value is 14% and the standard deviation divided by the injury criterion (the threshold for serious neck injury) is 8%. Maximum head acceleration was under 35 times the acceleration of gravity (g) and the spikes are of very short duration so that the HIC was well below injury levels in all three of the tests with dummies. Vertical neck compression in the three tests is shown in Figure 9.

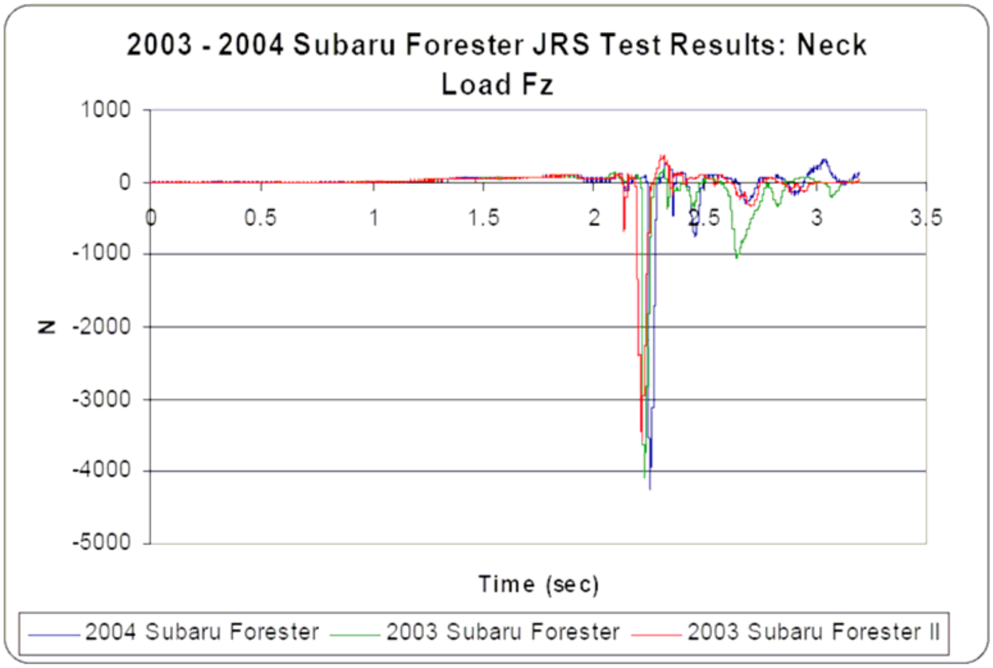

Figure 9. Vertical neck loads in the three tests of Subaru Foresters with dummies in the driver (initially trailing) seat. This is the seating position under the major roof crush. Note that none of the forces significantly exceeds 4,000 Newtons and that the traces are very similar.

Assessment of Results. These tests provide a strong indication of the repeatability of the JRS whether tested using standardized structures or using actual production vehicles. While there are no generally accepted standards for determining repeatability in automotive crash testing, two series of such tests have been conducted and analyzed. The first was a series of 35 mph frontal barrier crash tests of fourteen 1982 Chevrolet Citations with dummies conducted for NHTSA by three test facilities.[5]

The authors state that, ". . . the number variation from the sites participating in the RTP is approximately 10 percent." However, the standard deviation of the driver HICs was 21% of the average value while it was 10% for the passenger HICs. Time shifts in the data were also found to be roughly 10% of the duration of the event.

The authors described variation in the vehicle responses:

> An examination of the vehicle engine cradle revealed that different load paths developed during the crash event. . . . the bending at the cutout of the engine cradle members varied.

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[5] Machey, John M. and Charles L. Gauthier, *Results, Analysis and Conclusions of NHTSA's 35 MPH Frontal Crash Test Repeatability Program,* Office of Marketing Incentives, National Highway Traffic Safety Administration, Washington, D.C.: 1984. SAE 840201.

> In some vehicles, both left and right side buckled, some on the left and others only the right member buckled.
>
> In addition, the buckling of the floor pan and toe board varied from vehicle to vehicle and the separations between floor pan sections varied as did the separations at the rocker panel areas. Weld failures also occurred in the floor pan, some welds pulled parent metal, others failed at the weld joint.

These observations illustrate the differences in vehicle crash performance even when they are all assembled sequentially and are as identical as the manufacturer could make them on a regular assembly line. The authors also cited differences among test facilities, procedures, and dummies as contributing to the differences in the test results. Although not explicitly stated, the authors implied that variation of less than 10 percent in critical measurements was an acceptable level of repeatability. This level has been generally accepted in that NCAP testing has been used to rate vehicles for the last 27 years and presented to the public as a useful comparative measure of vehicle safety.

The Insurance Institute for Highway Safety (IIHS) also conducted a study of repeatability of its frontal offset crash tests.[6] In these tests of two models of each of seven vehicle models, the weights of the test vehicles, impact speeds, and degree of overlap were very well controlled.

They noted significant differences in the peak longitudinal accelerations of the vehicles, but attributed them to instrumentation rather than actual performance differences. The velocity curves as a function of time during the impacts were quite close. They found some differences in intrusion in the vehicles' interiors. The largest differences were in larger passenger cars and averaged roughly 25% of the total intrusion which averaged about 15 cm. The largest differences were only about 8 cm. With one exception, the average difference in steering wheel intrusion was 2 cm out of an average of 11 cm. These differences may be more a function of vehicle differences than test variability.

The differences in HICs and chest deflections between the two tests of each of four cars tested and reported both averaged 11 percent. Leg and foot measures had greater differences. The authors concluded:

In summary, because differences between intrusion measurements, restraint system observations, and dummy injury measures in repeated tests generally were small compared with differences between rating categories, the Institute's overall crashworthiness evaluations would not be expected to change as a result of repeated tests. In cases where there is somewhat greater variability, a rating change of more than one category appears unlikely. Thus, the repeatability of modern vehicle performance in a frontal offset crash test is sufficient for making evaluations of the crash protection provided by different designs.

The IIHS research endorses the position that variation of roughly 10 percent in key measurements made in crash tests indicates an acceptable level of variation in tests deemed to be repeatable.

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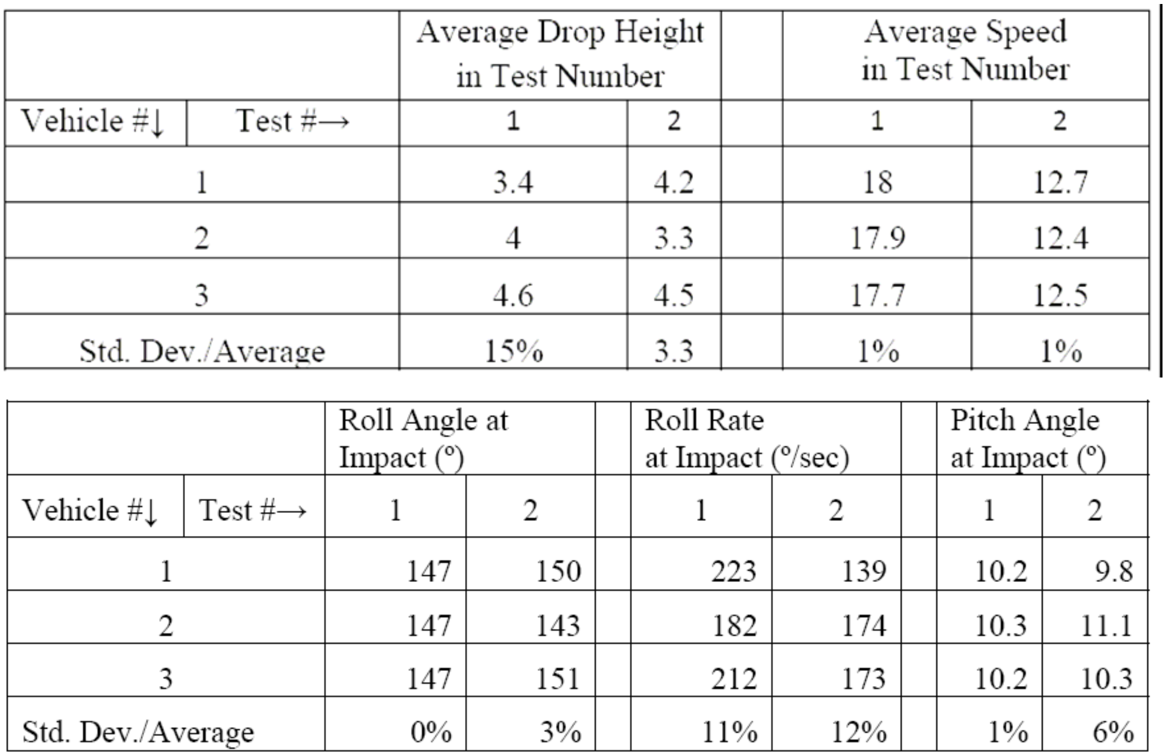
[6] Meyerson, Susan L., David S. Zuby, and Adrian K. Lund, *Repeatability Of Frontal Offset Crash Tests*, Insurance Institute for Highway Safety, Sixteenth International Experimental Vehicle Conference, 98-S 1 l-0-02, Winsor, Ontario: 1998.

In the JRS tests, Table 1 shows some of the parameters of the JRS Forester tests. The only parameter that has a somewhat high value for the standard deviation divided by the average value is drop height. Note, however, that the differences are fractions of an inch.

Most of the other parameters are well controlled: with variation well under 10%.



		Average Drop Height in Test Number			Average Speed in Test Number	
Vehicle #↓	Test #→	1	2		1	2
1		3.4	4.2		18	12.7
2		4	3.3		17.9	12.4
3		4.6	4.5		17.7	12.5
Std. Dev./Average		15%	3.3		1%	1%

		Roll Angle at Impact (°)			Roll Rate at Impact (°/sec)			Pitch Angle at Impact (°)	
Vehicle #↓	Test #→	1	2		1	2		1	2
1		147	150		223	139		10.2	9.8
2		147	143		182	174		10.3	11.1
3		147	151		212	173		10.2	10.3
Std. Dev./Average		0%	3%		11%	12%		1%	6%

Table 1. Basic JRS test parameters for the Forester tests.

In our JRS tests, the curves of vertical road load and the maxima were very well coordinated in the first set of tests. There was somewhat more variation in the second tests which is probably the result of minor differences in roof damage from the first tests.

The standard deviation divided by the average value for roof crush and intrusion rate at the A pillar, where crush is greatest, was 5 to 7 percent in the first test series and roughly double these values in the second test series. Again, the greater deviation in the latter tests is probably due to minor differences in the damage from the first tests. No repair or alterations were made to the vehicles between the first and second test except to install dummies.

The traces of neck load as a function of time are very similar, showing peaks of 3,573; 4,104 and 4,240 Newtons at around 2.2 seconds in all three tests. These values are substantially below the threshold for serious neck injury of around 7,000 Newtons.[7] The standard deviation divided by the average value is less than 9 percent and divided by the serious neck injury

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[7] Friedman, D. and Nash, C.E., "A Rollover Human/Dummy Head/Neck Injury Criteria," 2007 ESV Conference.

criterion is 5 percent. These neck loads are consistent with the roof intrusion speed over the dummy occupant in these tests.[8]

The results of this testing showed a high level of repeatability. Key measurements in the tests showed variation (the standard deviation divided by the average value) of less than 10 percent and an even lower variation when compared with threshold values. This is consistent with the conclusions of the NHTSA and IIHS scientists concerning whether a vehicle crash test is repeatable. Thus, we have demonstrated that the JRS is at least as repeatable as the tests used routinely in the New Car Assessment Program and by the Insurance Institute for Highway Safety.

These tests also suggest that even where the vehicles are not exactly matched (i.e. the used vehicles that were the subjects of this testing, one of which was built a year later than the others and one of which had moderate crash damage that did not involve the roof or supporting structures), the results of JRS testing still produces acceptable repeatability.

JRS Tests of Contemporary Vehicles

The recent model year vehicles selected for JRS testing under the Santos Family Foundation program are from a list of passenger cars and SUVs that have been tested by NHTSA using the one and two-sided FMVSS 216.[9] Thus far, C*f*IR has tested a 2007 Toyota Camry, a 2006 Hyundai Sonata, and a 2006 Chrysler 300. These vehicles have single side FMVSS 216 strength-to-weight ratios (SWR) of 4.3, 3.2, and 2.5, respectively.[10]

Test Procedure. The vehicles were tested at a pitch angle of 5º for the first test and 10º for the second test. The road speed was 15 mph, the vehicle is dropped 4 inches, the vehicle was at a roll angle of 147º, and the roll rate was 160º/second at the time of first roof impact.[11]

These vehicles were suspended on mounts at the rear and at the front in a manner that permits them to roll freely and be dropped, passenger side (the near side) leading.

Four string potentiometers were placed between the approximate longitudinal roll axis of the vehicle and the roof structure at the top of the driver's side A-pillar and B-pillar, at the header inboard of the A-pillar and at the top of the passenger's side A-pillar.

An instrumented, restrained Hybrid III test dummy was placed in the driver's seat (the initially trailing side in this test which is the most vulnerable seating position in a rollover). The dummy was set up in the normal manner except that the right shoulder was tightened to prevent contact with the forward roof string potentiometers. The dummy was instrumented with string potentiometers under the seat and lateral to the head of the dummy. The dummy also had upper and lower neck load cells. For the first roll, the dummy was in a standard seating position based upon FMVSS 208 recommendations. For the second roll, the dummy's torso was pitched forward to increase the neck angle 10 degrees and the seat was moved rearward to place it in a more realistic position for a rollover condition. Seat belt load cells were used to measure belt tension.

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[8] Friedman, et. al., "Human/Dummy Rollover Falling (Excursion) Speeds" 2007 ESV Conference.

[9] 73 FR 5484, at Tables 2 and 3 (Jan 30, 2008).

[10] Id at Table 2.

[11] The test parameters are nominal target values. Actual parameters were within a few percent of these values.

Six vertical and two lateral load cells were placed in the moving roadway to record the impact characteristics of the test. Two string potentiometers were placed on the fixture support towers to record vehicle vertical motion characteristics during the test. One string potentiometer was located in the front tower and the other was located in the rear drop tower. A roll encoder was placed on the cable pulley which pulls the moving roadway to record the roadway velocity throughout the test. Another roll encoder was placed on the shaft of the vehicle roll axis to determine the vehicle roll angles during the test.

Rollover Occupant Injury. Table 2 provides the basic results of these tests as they relate to the potential for injury for the three vehicles tested to date. Three measures used to evaluate the performance of the vehicles tested in this program include: (1) peak dynamic roof crush, (2) residual roof crush, and (3) peak crush intrusion speed. NHTSA has concluded that the residual roof crush is such that if it leaves negative headroom for a 50th percentile male, the probability of occupant head, face or neck injury increases dramatically. As can be seen from Table 2, the peak dynamic intrusion is typically 50 to 100% greater than the residual intrusion.

Most experts in the biomechanics of crash injury concur that the threshold for neck injury is a head impact speed of about 7 mph.[12] On the second roll, all three tested vehicles exceeded this value and the Chrysler exceeded it in both rolls. The residual roof crush for the 2.5 SWR Chrysler 300 leaves negative headroom on both JRS tests at 5.6 and 7.4 inches of residual crush at the A-pillar while the 3.2 SWR Hyundai Sonata had 2.6 inches of residual crush at the A-pillar on the first roll. The 4.3 SWR Toyota Camry had the least residual roof intrusion on the first roll at 1.6 inches but 4.3 on the second roll. Note that all three vehicles had little residual roof intrusion on the near side of the vehicle which demonstrates the futility of a single side test for FMVSS 216.

Based on both experimental tests and the statistics of real world accidents, NHTSA has established that if the neck injury criterion, Nij exceeds 1, there is a 15 percent probability that the occupant will suffer an AIS 3 or greater neck injury. If fact, NHTSA has established an Nij of 1.0 as the compliance level required under FMVSS 208 for a frontal crash test. Both the Chrysler and the Hyundai had Nij's significantly higher than that at 1.79 and 1.63 respectively showing marginal to poor performance in these tests.

The following is a detailed description of the results of the tests of these three vehicles.

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[12] Sances et al, “Biomechanical Modeling of Motor Vehicle Collisions and Overview of Belt Restraint Analysis,” BioVision 2001 (2001); Sances et al, “Spinal Injuries with Vertical Impact,” in Mechanics of Head and Spint Trauma (1986); Nusholtz et al, “Cervical Spine Injury Mechanisms,” SAE 831616 (1983); Sakurai et al, “Study on Passenger Car Rollover Simulation,” 13th ESV Conference (1991); Viano, David C., "Concussion in Professional Football: Biomechanics of the Striking Player -- Part 8," Neurosurgery 56:266-280, 2005; Bidez, Martha W., John E. Cochran, and Dottie King, "Roof Crush as a Source of Injury in Rollover Crashes," March 30, 2005, submitted to Docket NHTSA-2005-22143.

Vehicle	Roll	Peak Dynamic Crush (inches)[13]	Peak Crush Speed (mph)	Residual Roof Crush (inches)	Peak Neck Load (N)	Neck Injury Criteria
2006 Chrysler 300 SWR = 2.5	1	8.4	7.5	5.6	5598	1.79
	2	10.4	10.6	7.4	1979	0.44
2006 Hyundai Sonata SWR = 3.2	1	4.7	5.0	2.6	4835	1.63
	2	6.9	7.2	N/A	3457	1.15
2007 Toyota Camry SWR = 4.3	1	3.4	5.0	1.6	4211	0.78
	2	10.2	8.2	4.3	2669	0.76

Table 2. Second (Far) Side Data from tests of contemporary passenger cars of varying FMVSS 216 roof crush resistance (strength-to-weight ratio – SWR). Note that the peak dynamic crush in roll 2 for the Toyota occurred at the windshield header, not the top of the A pillar. The Hyundai Sonata data for roll 2 came from analysis of film and data traces.

Vehicle	Roll	Peak Dynamic Crush (inches)[14]	Peak Crush Speed (mph)	Residual Roof Crush (inches)
2006 Chrysler 300 SWR = 2.5	1	1.0	2.4	0.4
	2	1.8	2.9	0.8
2006 Hyundai Sonata SWR = 3.2	1	1.0	1.2	0.2
	2	1.8	1.3	0.6
2007 Toyota Camry SWR = 4.3	1	1.2	2.3	0.2
	2	2.3	1.2	-0.4

Table 3. First (Near) Side Data from tests of contemporary passenger cars of varying FMVSS 216 roof crush resistance (strength-to-weight ratio – SWR)

Chrysler 300. Figure 10 shows the Chrysler 300 after the first and second rolls. Note the extensive windshield header buckling and intrusion of the roof panel over the driver position.

The Chrysler's curb weight is 3,726 pounds and its test weight was 3,941 pounds. It registered a maximum road impact load with the second side of the roof of 24,100 pounds on the first roll test and 43,085 pounds on the second. Belt loads were nominal during the test. The residual roof intrusion at the A pillar was 5.6 inches after the first roll and 7.4 inches after the second. The intrusion at the roof buckle was even greater. According to NHTSA, this would significantly increase the probability of a head, face or neck injury in a rollover.

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[13] The peak dynamic crush on the second roll is the total of the residual roof crush from the first roll and the additional dynamic crush during the second roll. The residual roof crush on the second roll is the total of the residual roof crush from the first roll and the additional residual crush on the second roll.

[14] The peak dynamic crush on the second roll is the total of the residual roof crush from the first roll and the additional dynamic crush during the second roll. The residual roof crush on the second roll is the total of the residual roof crush from the first roll and the additional residual crush on the second roll.

Figure 10. The 2007 Chrysler 300 after the first JRS roll test (left) and second roll.

The Chrysler 300 barely met the 2.5 SWR roof crush resistance value proposed by NHTSA in 2005, and did so in its two-sided test. However, the roof showed serious performance deficiencies in our dynamic testing. The rollover occupant protection capability of this vehicle as poor based on the amount and speed of roof intrusion, and on the high peak neck load and neck injury criterion in the first roll test. If this were a FMVSS 208 compliance test, the Nij levels would fail the vehicle.

Hyundai Sonata. Figure 11 shows the 2006 Hyundai Sonata after the first and second rolls. The damage to the initially leading side of the roof increased substantially in the second roll, which is somewhat unusual in both JRS tests and actual rollovers, and indicates that the damage to the second side in the first test substantially weakened the roof overall.

Figure 11. The 2007 Hyundai Sonata after the first JRS roll test (left) and second roll.

The Sonata's curb weight is 3,266 pounds and its test weight was 3,501 pounds. It registered a maximum road impact load with the second side of the roof of 17,711 pounds during the first roll and 31,380 during the second. Belt loads were nominal during the test. The residual roof intrusion at the A pillar was 2.6 inches after the first roll and could not be measured after the second because of interference between the dummy and the string potentiometer. Although the intrusion over the driver position was reasonable, the tenting of the windshield header and damage to the roof on the passenger side indicate problems with the overall structural integrity of the roof of this vehicle.

The 3.2 SWR Sonata would meet NHTSA's proposed 2.5 SWR roof crush resistance criteria in the FMVSS 216 test, but its performance showed serious structural weakness in the JRS test and a significant probability of injury to the driver in these rollover tests. The rollover occupant protection performance of the Hyundai Sonata is only marginal based on the peak neck load and neck injury criterion in the first roll test, the peak roof intrusion speed in the second roll, and the excessive intrusion of the passenger side roof. If this were a FMVSS 208 compliance test, the Nij levels would fail the vehicle.

Toyota Camry. Figure 12 shows the 2007 Toyota Camry after the first and second roll tests on the JRS.[15] The vehicle looked fairly good after the first roll test (although there was incipient damage at the left end of the windshield header), but developed significant buckles in the windshield header in the second roll. Toyota uses high strength steel in the pillars and roof rails at the side of the roof of its Camry and Corolla models, but they have weak windshield headers as demonstrated in this test.

Figure 12. The 2007 Toyota Camry after the first roll JRS test (left) and the second.

The Toyota's curb weight is 3,260 pounds and its test weight was 3,176 pounds. It registered a maximum road impact load with the second side of the roof of 19,242 pounds on the first roll test and 25,038 pounds on the second. Belt loads were nominal during the test. The residual roof intrusion at the A pillar was 1.6 inches after the first roll and 4.7 inches after the second. The intrusion at the roof buckle was somewhat greater. This vehicle had only marginal headroom after the second roll test according to NHTSA's headroom criterion.

The Toyota Camry substantially exceeded NHTSA's proposed roof crush resistance criterion of a SWR of 2.5. However, the performance of the windshield header shows that performing well in the FMVSS 216 test is not a sufficient condition for good roof crush resistance. The attached paper by Nash shows that this weakness affects the performance of Toyota sedans in actual rollovers captured by the National Accident Sampling System (NASS).

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[15] The front end damage to this vehicle occurred before these tests were conducted. The vehicles were donated by State Farm Mutual Auto Insurance Company after they were declared a total loss by the insurer. Detailed inspection of all vehicles tested in this program revealed no damage to the relevant occupant compartment structures.

The rollover occupant protection of the Camry is fair. The good side structure of the roof is compromised by the weak windshield header which permitted high roof intrusion speed in the second roll test. The real world performance of the Camry gives little confidence that the Camry's rollover performance is much better than average. These test results show why the conditions of the current FMVSS 216 test, even if repeated on the second side, are not adequate to ensure good roof crush resistance.

Various JRS tests of vehicles with FMVSS 216 SWR less than 2.5, including the Chrysler 300, have sustained at least 127 mm (5 inches) of residual crush in all but one case (which was only slightly less than 127 mm). These tests, which were summarized in a recent C*f*IR submission show that setting a FMVSS 216 performance level of 2.5, whether in a one or two-sided test, would not be adequate to reduce rollover injuries significantly.

Auto companies have demonstrated compliance with FMVSS 216 with margins as low as 0.8% pr a SWR of 1.51 based on the present 216 standard of a 1.5 SWR.[16]

Benefits and Deficiencies of Various Tests

We are disappointed that NHTSA has not considered using a dynamic test for rollover occupant protection in this rulemaking. However, we believe that rollover occupant protection can be dramatically improved even with a well-crafted quasi-static test. Such a test must have a roll angle greater than 25º on at least one side, and a pitch angle of at least 10º to ensure that the roof receives appropriate shear stress. We also strongly advocate the use of the Jordan Rollover System in a New Car Assessment Program rating for rollover occupant protection.

We have evaluated the various tests:

- FMVSS 216 quasi-static test (5º pitch, 25º roll). The only advantage of this test is that it has been in use for decades and therefore is reasonably inexpensive to conduct. NHTSA's two-sided tests show significant differences in the second side performance of a significant number of vehicles. The disadvantages of this test are that it does not put sufficient lateral stress on a roof structure because of the shallow roll angle, and that it does not realistically stress the A pillar because of the shallow pitch angle. The attached paper shows that this test does not identify deficiencies in roof performance even for vehicles that have a SWR in excess of 4.
- M216 quasi-static test (10º pitch, 25º roll on the first side, 10º pitch, 40º roll on the second side). This test overcomes the principal deficiencies of the FMVSS 216 test because of its increased pitch and roll angles. Nevertheless, it is still a quasi-static test and does not apply forces to the roof dynamically as occurs in an actual rollover.
- FMVSS 208 Dolly Rollover test. This test provides reasonably realistic dynamic test conditions. It is widely used in the industry for development of advanced rollover protection systems such as window curtain air bags. It has also passed the legal test of repeatability because the initial conditions of the test can be closely controlled. However, because the vehicle is not controlled once it is released, the consequences of the test may vary significantly. Furthermore, the only criterion for passing the test is that a dummy

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[16] See 1999 Ford Explorer FMVSS 216 Certification Test, in NHTSA Docket 2005-22904, Document ID # NHTSA-2005-22904-0001, a copy of which is incorporated herein by reference.

must be completely contained throughout the rollover. Nevertheless, a vehicle that is designed to pass the test can do so repeatedly. A vehicle that is not may or may not pass a specific run of the test.

- Controlled Rollover Impact System (CRIS). This test requires expensive test equipment, a large test track, and is expensive to run. In tests that have been conducted to date, the wheels are left on the vehicle during the test, and as a result the vehicle must be dropped from an unrealistic height to its roof.
- Jordan Rollover System test. This dynamic test is highly controlled and has been proven to be highly repeatable. The JRS equipment and cost of running tests are modest. The test conditions can be widely varied to emulate actual rollover conditions. There is now a significant body of test data on vehicles of varying roof strength.

Benefits and Costs of Roof Crush Resistance

In assessing the benefits of roof crush rulemaking, NHTSA has not considered the substantially greater rollover casualty rates in SUVs and pickups that would easily justify more stringent requirements for these vehicles. This is not to suggest lower levels of protection for passenger cars, but to note that the benefits of substantially increased roof crush resistance in light trucks, and particularly SUVs, would be two to three times as great as the benefits for passenger cars, and would easily justify a strong roof crush requirement.

Some manufacturers – including Toyota, General Motors, Ford, and Subaru – are already producing cars and light trucks with substantially stronger occupant compartments in recognition of the occupant protection principles put forth by DeHaven. These manufacturers are using high strength steel in key parts of the occupant compartment structure and one (Subaru) is in effect using a roll bar around the B pillar area to improve side impact load distribution. These auto makers have made such structural changes primarily to improve occupant protection performance in offset frontal and side impact crashes. The cost of increased roof crush – which can be successfully engineered into a vehicle only by improving occupant compartment strength generally – must be apportioned among all crash modes. No more than one-third of the cost of improved roof strength should be allocated to improved rollover occupant protection.

For example, the 2007 Toyota Camry and 2003-04 Subaru Forester which we tested under the Santos Family Foundation grant, had substantially upgraded structures to improve their performance in IIHS side impact rating tests and NHTSA new side impact standard phased in beginning on September 1, 2009. This structure made the Camry and Forester perform better in the tests conducted on the JRS and in NHTSA's FMVSS 216 testing for this rulemaking. In performing a cost benefit analysis for upgrading FMVSS 216, NHTSA should subtract all costs associated with upgrading vehicles to meet the new FMVSS 214 or to improve performance on IIHS' side impact test rating program..

Conclusion

The dockets (NHTSA 1999-5572, NHTSA 2005-22143, and NHTSA 2008-0015) have very extensive information and test data relating to this rulemaking. This evidence supports a much stronger side impact standard than the single side 2.5 SWR in the original notice of proposed rulemaking or the two sided 2.5 SWR in the supplemental notice of proposed rulemaking. Unless NHTSA goes forward with a final rule of at least 3.5 SWR in a two sided tests now and a dynamic test based on the JRS within the next three years, many thousands of lost lives and serious injuries will result.

Sincerely,

Clarence M. Ditlow Executive Director	Carl E. Nash, Ph.D.

Does a High Strength to Weight Ratio in FMVSS 216 Necessarily Mean Good Rollover Performance?

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March 7, 2008

In recent government roof crush resistance tests of light motor vehicles (Federal motor vehicle safety standard 216) the vehicles of one manufacturer, Toyota, stood out. Figure 1 gives a summary of the results of these tests plus the results of a test of the Toyota Corolla. These tests show exceptionally high strength-to-weight ratio SWR values for Toyota's vehicles. These high numbers generally carry over to the second side when tested using the same procedure.

Year	Model	First Side SWR	Second Side SWR
2007	Scion tC	4.6	4.3
2007	Takoma (pickup)	4.4	3.9
2007	Camry	4.3	4.7
2007	Yaris	4.0	3.4
2006	Corolla	4.2	---

Figure 1. Strength-to-weight ratios of a selection of recent model Toyota light vehicles in Federal motor vehicle safety standard 216 quasi-static tests of roof crush resistance.

The Center for Injury Research has tested two Toyota passenger cars, the Corolla and the Camry, on the dynamic Jordan Rollover System (JRS). In those tests, a weakness in the structure of the tested vehicles became obvious: the windshield header is weak and likely to buckle under dynamic loading (see Figure 1).

Figure 1. Photographs of a 2007 Toyota Camry roof after one roll and after two rolls in a JRS test showing the buckling of the windshield header in this vehicle. The Toyota Corolla showed similar buckling in a JRS test.

In order to see whether the performance found in these tests carry over to vehicles in actual rollovers, we searched 2002-2006 National Accident Sampling System (NASS) files for all rollovers of Toyota, Scion, and Lexus models from 2003 through the present model year. We eliminated cases where the roof struck a tree or other object that caused massive crush during the rollover, cases where there was no vehicle inspection, and one case where a fire rendered the vehicle nearly unrecognizable. We found a total of 34 Toyota cases and 3 Lexus cases. The cases are generally described in Tables 1 and 2. Only injuries greater than AIS 1 were noted.

Except for a couple of cases, we found that Toyota roofs generally looked good after a rollover except that in many cases the windshield header buckled. This behavior mirrors the results of the JRS tests.

Because NHTSA's weighting factors are probably not reliable for analyses of these rollover cases, we were not able to determine the statistical significance of results of these cases. Nevertheless, a number of general conclusions can be drawn from them.

- About half of the vehicles that rolled over were passenger cars.
- We estimate that up to 27 of the rollovers involved either a collision before the rollover or conditions where electronic stability control (ESC) would have been unlikely to have prevented the rollover. Passenger cars were more likely to have had their rollovers initiated by a collision or other factors that ESC would not have prevented.
- Only six of the rollovers involved more than one roof impact with the ground (i.e. 6 or more quarter rolls).
- Three belted occupants – two in light trucks – suffered moderate (AIS 2) head injuries from contact with the roof. One, a restrained driver in a Corolla, suffered severe (AIS4) head injuries from partial ejection (2005-78-45). The vehicle had major roof crush over the driver position that repositioned the driver's side window frame so as to facilitate the partial ejection. This was the only vehicle in this study that suffered major roof crush (other than header buckling) from a flat ground rollover.
- Five other occupants suffered AIS 2 injuries, only one of which was to the head, face or neck. That one was a restrained driver whose injury came from contact with the steering system. Three occupants suffered AIS 3 arm or leg injuries, some of which were from partial ejection. One 75 year old occupant suffered a fatal neck injury from a side impact by a motorcycle before the rollover and another suffered a fatal thoracic injury from a side impact by a van.
- Although there was surprisingly little buckling or other serious damage to the A, B, or C pillars or to the roof rails, 19 of the vehicles had some intrusive buckling or tenting damage to the windshield header. In many of these cases, the header damage caused buckling of the roof panel.

NASS Case No.	Year	Model	No. of ¼ Rolls	Description of Roof Damage	Other Factors
2004-9-56	2004	Camry sedan	15	Minor header tenting	Greater tenting over rear window - unbelted rear seat pass. ejected - moderate injuries
2005-42-122	2005	Camry	2	Minor header buckle	
2005-43-169	2004	Camry	6	Minor	Unbelted 75 y.o. occ. had a serious neck injury
2006-42-140	2005	Camry	2	Minor	Minor collision first – mod. sternal fracture
2006-72-93	2004	Camry	4	Header tented	Moderate collision first
2006-72-104	2004	Camry	2	Header buckled	Moderate collision first serious arm & leg inj.
2004-03-150	2004	Corolla sedan	2	Header buckled	Minor collision first restrained driver had moderate shoulder inj.
2004-43-99	2003	Corolla	6	Header buckled	Serious arm injury
2004-48-103	2003	Corolla	2	Very minor	Minor collision first
2004-48-285	2005	Corolla	4	Header buckled	Hit guardrail first
2005-47-37	2005	Corolla	3	Header buckled	Up small embankment unknown injuries
2005-78-45	2005	Corolla	6	Major roof crush over driver	Partially ejected driver had severe head injury
2006-41-207	2005	Corolla	2	Header buckled	Side MC impact before caused fatal head inj.
2006-43-86	2006	Corolla	2	Header buckled	Collision first
2006-78-119	2006	Corolla	9	Minor	Moderate face inj. from steering
2004-82-60	2004	Prius sedan	2	Minor	Minor collision first
2004-75-194	2005	Scion tC coupe	2	Very minor	Major collision first moderate head injury
2005-79-75	2006	IS-300 sedan	4	Minor	Hit guardrail first

Table 1. NASS cases (through 2006) involving relatively simple rollovers of 2003 and later Toyota cars.

NASS Case No.	Year	Model	No. of ¼ Rolls	Description of Roof Damage	Other Factors
2005-43-180	2006	RX-400 Hybrid	4	Header buckled	Collision first
2006-75-154	2004	RX-330 SUV	4	Minor	Hit very small trees
2003-48-48	2003	Highlander SUV	2	Header buckled	Unbelted driver had AIS 2 head injury
2005-50-154	2005	Sequoia SUV	3	Minor	Minor collision first
2006-48-40	2004	4Runner	2	Moderate RF corner crush	Minor side impact first
2005-48-12	2005	Scion XB van	2	Minor	Minor collision first
2006-82-44	2006	Scion XB	4	Moderate	Major collision first ejected pass. died

NASS Case No.	Year	Model	No. of ¼ Rolls	Description of Roof Damage	Other Factors
2003-76-151	2003	Tacoma pickup	4	Header tented	
2004-9-142	2004	Tacoma	2	Header buckled	Minor collision first
2004-43-145	2003	Tacoma	6	Header buckled	Moderate head injury
2004-43-335	2004	Tacoma	4	Minor	
2004-76-146	2003	Tacoma	2	Header buckled	
2005-48-30	2003	Tacoma	4	Minor header buckle	Moderate collision before - mod. foot injury
2005-75-21	2004	Tacoma	3	Header buckled	Not flat ground R/O
2005-79-111	2003	Tacoma	2	Header buckled	Minor collision at end
2006-43-33	2006	Tundra pickup	5	Minor	Major side impact first – fatal thoracic injury to unrestrained pass.
2006-48-197	2004	Tundra	4	Moderate RF corner crush	Towing large trailer
2006-78-39	2003	Tacoma	3	Minor	Moderate arm injury
2006-79-14	2004	Tacoma	1	Minor	Moderate collision first serious arm injury

Table 2. NASS cases (through 2006) involving relatively simple rollovers of 2003 and later Toyota SUVs, vans and pickups.

- Belt use was more common in these rollovers than in rollovers generally, although this may be typical of relatively new vehicles. In eight of the rollovers at least one occupant was not wearing a safety belt. Three of those occupants were completely ejected. All of the unbelted occupants suffered at least an AIS 2 injury. Four belted occupants suffered partial ejections, three suffering an AIS 2, an AIS 3 and an AIS 4 injury.

If these cases are reasonably representative, the rollover experiences of the Toyotas captured in NASS investigations does not appear to be substantially different from what would have been found from a similar sample of late model cars and light trucks in most respects. The obvious weakness of the windshield headers in these vehicles is troublesome, however.

A Toyota corporate representative[1] recently stated that the company added reinforcements to improve the Corolla's performance in the Insurance Institute for Highway Safety (IIHS) frontal offset crash test, not to improve rollover roof crush resistance. Toyota added or substituted about 7 pounds of high strength steel to the base of the A-pillar, the roof rails and the B-pillar for this purpose as shown in Figure 5. They did not strengthen the open section windshield header which buckled in our tests of this vehicle.

Inspections of the Toyota Corolla and Camry that were tested on the Jordan Rollover System showed strengthened B pillars and posts and a stronger roof bow between the B pillars. These structures prevent intrusion and transfer the load from side to side in dynamic side impact testing. They also greatly improve FMVSS 216 peak values because the platen engages the B pillar area early in that test. By contrast, the windshield header is very weak and poorly designed to absorb loads that are concentrated at the top of the A pillar.

Toyota could have substantially improved roof performance in rollovers by making the windshield header a closed section and perhaps by using the same higher strength steel that was used in the pillars and roof rails. The FMVSS 216 test is a poor test of roof crush resistance because it does not stress the windshield header in a manner that would show the weakness of the Toyota windshield header.

Not surprisingly, the recent model Camry has 5 star New Car Assessment Program ratings for both front and side impacts, and the Corolla has 5 star frontal crash ratings and 4 star side impact ratings. The Camry got a "good" rating in the IIHS offset frontal and (if equipped with side impact air bags) in the side impact tests. The Corolla also got a "good" rating in the offset frontal tests but only an "average" rating even when equipped with side impact air bags.

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[1] Deposition of Motoki Shibata, taken on October 26, 2006 in *Basco vs. Toyota Motor Company*.

A stronger windshield header would have prevented the buckling in two of the cases where there was an AIS 2 head injury (2003-48-48 and 2004-43-145), and would have reduced the crush in case 2005-78-45 which would have substantially reduced the severity of the injury in that case. Three head injuries of these severities is about what one would expect from a representative sample this size.

Most, if not all of the vehicles in this study probably exceeded any level of performance being considered by NHTSA for a one or two-sided FMVSS 216 test at 5º pitch and 25º roll such as a strength-to-weight ratio of 3.5. This is why it is important that if there is a quasi-static test of roof strength, it must include a second side test at a pitch of 10º and a roll angle of 40º to realistically stress all parts of the roof structure. Structural buckling of any kind has the potential for inflicting occupant injury and for increasing the potential for window failure and partial or complete ejection. A dynamic test such as the Jordan Rollover System test or the FMVSS 208 dolly rollover test would more realistically test the structural integrity of a roof.

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