BIDEZ
& ASSOCIATES

November 21, 2005

Docket Management Facility
U.S. Department of Transportation
400 Seventh Street, S.W.
Nassif Building, Room PL-401
Washington, D.C. 20590-0001

ATTN: Docket No. NHTSA-2005-22143

Dear Sir or Madam:

I have reviewed the National Highway Traffic Safety Administration's (NHTSA's) Notice of Proposed Rulemaking (NPRM) "Federal Motor Vehicle Safety Standard; Roof Crush Resistance" published at 70 Federal Register 162 on Tuesday, August 23, 2005. My area of expertise, biomechanical engineering, is particularly well suited to evaluate and comment on the scientific veracity of the NPRM in meeting the published purpose of Federal Motor Vehicle Safety Standard (FMVSS) 216, which is to reduce death and injury due to roof crush in rollover crashes.

An upgrade of the existing FMVSS 216 is long overdue; however, the current NPRM, if implemented as a final rule, will provide no additional protection to rollover occupants. A static, component test, irrespective of the test variables, simply has no scientific basis in injury prevention within the rollover crash environment. The arguments against more meaningful upgrades citing a likelihood of upsetting the balance within NHTSA's comprehensive rollover plan are disingenuous. How can a plan be considered comprehensive when absolutely no protection is offered to anyone in the back seat(s) of vehicles, particularly children? Has NHTSA considered the fact that the rate of MAIS 3+ injuries for children aged 4-12 years is 2-3 times higher in rollover crashes compared to all other crash modes!

The attached report supplements my research group's prior submission to Docket No. NHTSA-1999-5572. ***Readers are cautioned that this report includes very disturbing, graphic case studies with scene photos of real world rollover injuries.*** I have included these field reports to remind the Agency that my comments are decidedly not simply an academic argument. I urge the Agency to follow the lead of Volvo and utilize the existing FMVSS 208 dolly rollover test as a measure of occupant kinematics and injury prevention in rollover crashes. This rollover test is the only dynamic test of the entire occupant protection system with any biomechanical relevancy, which is currently utilized by all existing automotive manufacturers. Moreover, it is ALREADY an existing alternative compliance test for FMVSS 216, so arguments against the use of this test for purposes of rollover protection are puzzling, at best.

Sincerely,

Martha W. Bidez

Martha W. Bidez, Ph.D.

2100 Third Avenue North, Suite 410, Birmingham, AL 35203 T 205.326.6813 F 205.322.0766

ANALYSIS OF NHTSA'S ROLLOVER PLAN

Martha W. Bidez, Ph.D.
Professor, Department of Biomedical Engineering
University of Alabama at Birmingham
President, Bidez and Associates, Inc.

Submitted to Docket No. NHTSA-2005-22143
November 21, 2005

BACKGROUND

The rollover mitigation plan of the National Highway Traffic Safety Administration (NHTSA) seeks to "…reduce the likelihood of rollover crash events and to improve crashworthiness in such crashes, thereby saving lives and reducing serious injuries." [1]

September 2002 marked the plan's beginning when NHTSA formed four integrated project teams (IPTs) to conduct an in-depth review of the agency's four priority areas:

- Safety Belt Use
- Impaired Driving
- Rollover Mitigation; and
- Vehicle Compatibility

According to NHTSA, the comprehensive plans resulting from the work of its IPTs "Recommended strategies (that) were based on ***science, data and other available evidence***." [2] (Emphasis added). In February 2003, NHTSA senior management analyzed the IPTs' recommended strategies to determine which strategies the agency should pursue. The final agency plan for rollover mitigation strategies was published in the Federal Register on June 18, 2003. The plan included three proposed initiatives to mitigate rollover crashes:

1. <u>Vehicle Strategies</u>
   - Crash Avoidance
   - Crashworthiness
2. <u>Roadway Strategies</u>
   - Roadway and Roadside Improvements
3. <u>Behavioral Strategies</u>
   - Consumer Information Program

As part of the crashworthiness strategies, the NHTSA recently published a Notice of Proposed Rulemaking (NPRM) on August 23, 2005 "…to upgrade the agency's safety standard on roof crush resistance in several ways." [3]

1. Extend the application of the standard to vehicles with a Gross Vehicle Weight Rating (GVWR) of 4,535 kg (10,000 lb) or less
2. Increase the applied force to 2.5 times each vehicle's unloaded weight, and to eliminate the existing limit on the force applied to passenger cars
3. Replace the current limit on the amount of roof crush with a new requirement for maintenance of enough headroom to accommodate a mid-size adult male occupant.

This report documents fundamental flaws in the agency's "comprehensive rollover plan," in general, and NPRM, in particular, from a biomechanical engineering and scientific perspective.

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[1] NHTSA-2003-14622, p. 3
[2] Ibid, p. 4
[3] Docket No. NHTSA-2005-22143; Federal Register/Vol. 70, No. 162/Tuesday, August 23, 2005/Proposed Rules, p. 49223

SCIENTIFIC FLAWS

The NPRM suffers from a fundamental scientific flaw in that the proposed test methodology and outcome variables fail to support the stated purpose and specific aims of the Federal Motor Vehicle Safety Standard (FMVSS) No. 216, Roof Crush Resistance,

> "The purpose of this standard is to reduce deaths and injuries due to the crushing of the roof into the occupant compartment in rollover crashes."[4]

In order to achieve such a purpose, the agency must necessarily incorporate in its rulemaking the well known, published and broadly accepted biomechanical principles for injury prevention in rollover crashes.

1. Serious occupant injury in rollovers is not and cannot be predicted by a static test, either one-sided or two sided, as occupant injury severity depends upon **dynamic load variables, including load rate and degree of head entrapment.**

The scientific literature[1-9] is replete with cadaver studies, which conclusively demonstrate the rate dependence of serious (MAIS ≥3) injury of the head and cervical spine (Figures 1-2, Tables 1-2). When the head is not trapped by roof crush (i.e. unconstrained end condition), a threshold for catastrophic injury appears to be 3-4 m/s (7-9 mph).

Importantly, absolutely no serious spine or head injury is predicted by any published laboratory data under static or quasi-static tests such as the loading rate in the range of FMVSS 216 or the NPRM. Thus, at its most fundamental level, the NHTSA proposal to "upgrade" the FMVSS 216 test "…to reduce deaths and injuries due to the crushing of the roof into the occupant compartment in rollover crashes" is incapable of predicting occupant injury due to an inappropriate test methodology.

Restated, the existing FMVSS 216 test as well as the "upgrade" proposed in the NPRM are simply structural component tests, which have no scientific basis for predicting occupant injury in rollovers. The only scientifically valid test for serious occupant injury MUST necessarily be a ***dynamic*** test, which evaluates the entire vehicle occupant protection system.

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[4] FMVSS 216, Section S2. Purpose

FIGURE 1

AIS ≥ 3 Spinal Injuries

(Unconstrained - Head/Cervical Spine Component Tests)

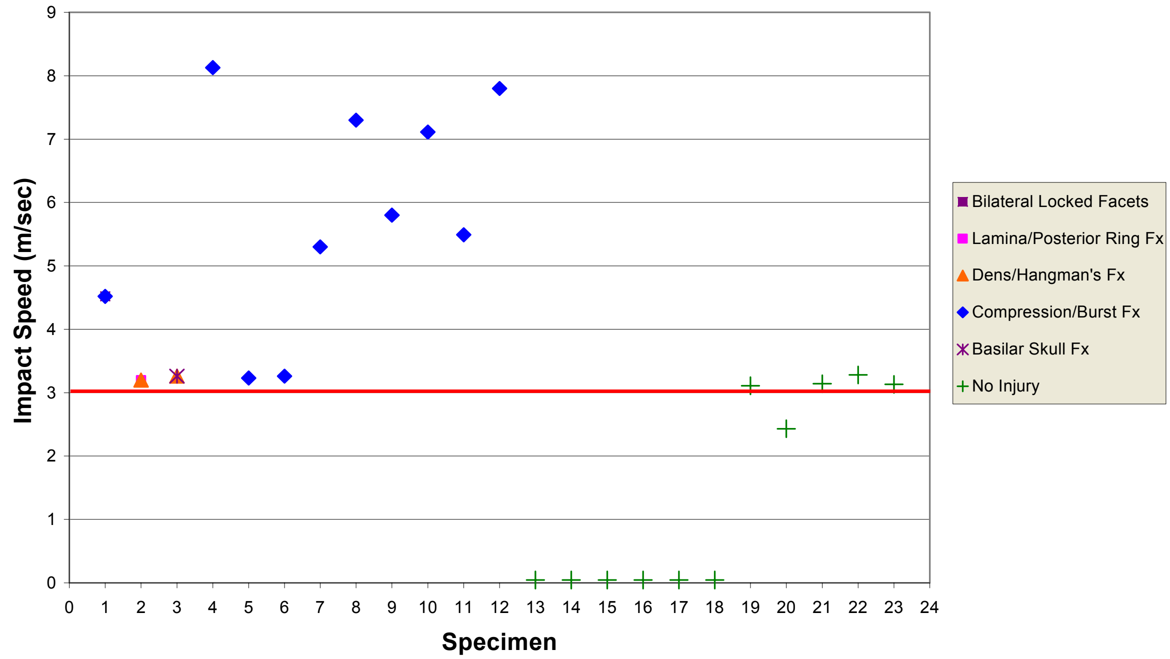


FIGURE 2

AIS ≥ 3 Spinal Injuries

(Unconstrained - Full Cadaver Tests)

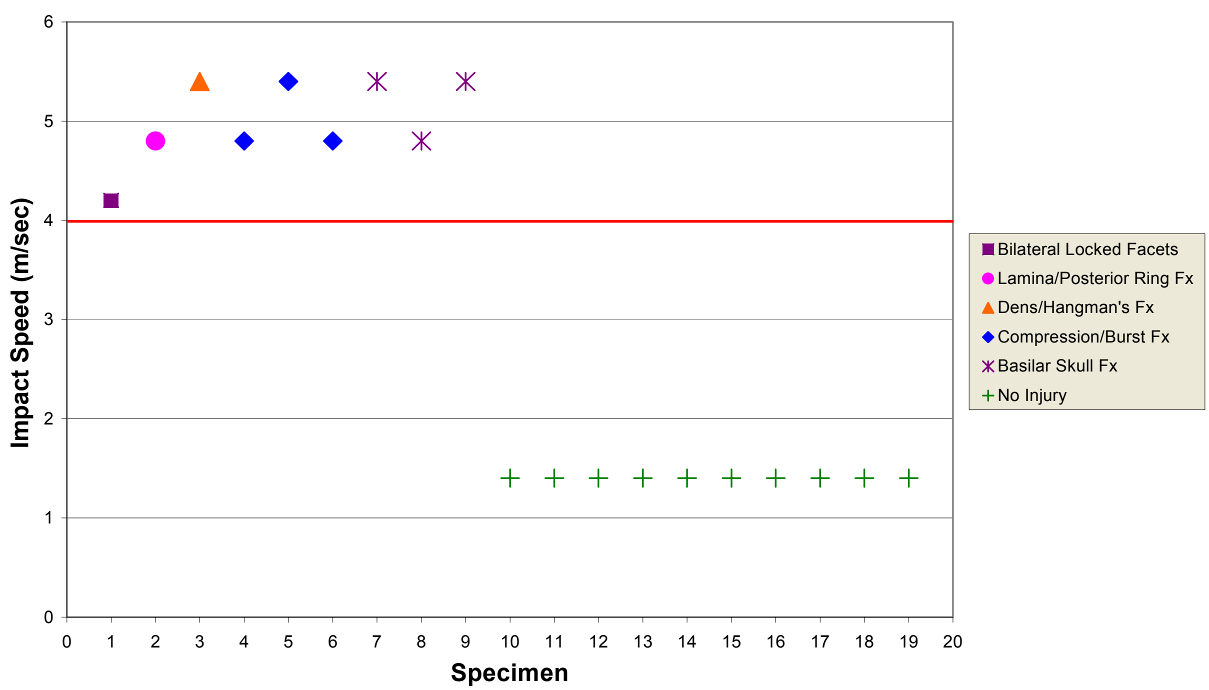


TABLE 1
AIS ≥ 3 Spinal Injuries
(Unconstrained - Head-Cervical Spine Component Tests)

Specimen #	Specimen Source Label	Impactor Speed (m/sec)	Injury
1	2[1,2]	4.52	Dislocation of C5 with respect to C6; C5 burst fx. with cord compromise
2	N24-R+0[4-8]; B[4-8]	3.20	C1 2-part fx. through the posterior ring; C2 Hangman's fx.
3	N18-R+15[4-8]; F[4-8]	3.26	Basilar skull fx.; C2 Hangman's fx.
4	4[1,2]	8.13	C6 anterior vertebral body compression fx.
5	N05-R+30[4-8]; G[4-8]	3.23	C3 burst fx.
6	N22-R+0[4-8]; C[4-8]	3.26	C1 3-part comminuted fx.
7	6[9]	5.3	Burst compression fx. of C5 vertebral body
8	1[9]	7.3	Wedge fxs. of C5 and C4 vertebral bodies
9	3[9]	5.8	Anterior compression(60%) of C3 vertebral body
10	5[1,2]	7.11	Anterior 2/3 of C3 vertebral body fx. and displaced 2mm
11	3[1,2]	5.49	Wedge compression fx. of C4
12	4[9]	7.8	Anterior compression (40%) of C4 vertebral body
13	A[3]	0.045	No injury
14	B[3]	0.045	No injury
15	C[3]	0.045	No injury
16	D[3]	0.045	No injury
17	E[3]	0.045	No injury
18	F[3]	0.045	No injury
19	D41-R+15[4-6]	3.11	No injury
20	N26-R+0[4-8]; A[4-8]	2.43	No injury
21	N11-R-15[4-6]	3.14	No injury
22	N13-R-15[4-8]; E[4-8]	3.28	No injury
23	UK3-R-15[4-6]	3.13	No injury

Note: Superscripts refer to reference citations (see Bibliography)

TABLE 2
AIS ≥ 3 Spinal Injuries
(Unconstrained - Full Cadaver Tests)

Specimen #	Specimen Source Label	Impactor Speed (m/sec)	Injury
1	HS77[1]	4.2	Anterior subluxation of C5 on C6 w/ bilateral locked facets
2	HS92[1]	4.8	C2 vertebral body and lamina fracture
3	HS84[1]	5.4	Type II Odontoid fracture
4	HS80[1]	4.8	T7 wedge compression fracture
5	HS86[1]	5.4	T4 burst fracture
6	HS81[1]	4.8	Shattering of T7
7	HS85[1]	5.4	Bilateral basilar skull fracture
8	HS88[1]	4.8	Right parietal skull fracture into base
9	HS87[1]	5.4	Occipital linear skull fracture into base
10	82L487[2]	1.4	No Injury
11	83L488[2]	1.4	No Injury
12	83L490[2]	1.4	No Injury
13	83L491[2]	1.4	No Injury
14	83L492[2]	1.4	No Injury
15	83L493[2]	1.4	No Injury
16	83L495[2]	1.4	No Injury
17	83L496[2]	1.4	No Injury
18	83L497[2]	1.4	No Injury
19	83L498[2]	1.4	No Injury

1. Yoganadan, N., Sances, Jr. ,A., Maiman, D., Myklebust, J., Pech, P., Larson, S., “Experimental Spinal Injuries with Vertical Impact” Spine 11(9) 1986

2. Nusholtz, G., Huelke, D., Lux, P., Alem, N., Montalvo, F. “Cervical Spine Injury Mechanisms” 831616 pgs 939-957

A series of case studies are presented in this report, which provide real world examples of the tragic consequences of a static FMVSS 216 test for predicting serious rollover injuries. Each case is classified according to (1) the type of predictable roof crush pattern, identified by Volvo in the development of the XC90 Sport Utility Vehicle (SUV) and (2) the type of predictable injuries that occur in real world rollover crashes.

CASE STUDY 1: Basilar Skull Fracture, Open

A restrained female driver (37 yrs, 62 inches, 111 lb) of a 2000 Ford Explorer rolled over during highway driving conditions with the SUV sustaining damage to the right A- and B-pillars, roof rail and driver's window frame (Figure 3). The driver was found dead at the scene, still restrained by her lap-shoulder belt (Figure 4). During the rollover, her head was partially ejected out the driver's side window when the dynamic, downward deflection of the upper window frame cleaved open her skull on the right side (Figure 5). The magnitude of the dynamic roof crush, which significantly exceeded the post-impact crush profile (Figure 3), was the cause of her death. The nature of the soft tissue wounds to her face and the location of the open skull fracture on the right (not left) side of her skull eliminated ground contact as the cause of death. She sustained a complete atlanto-occipital transection, a complete transection of her brainstem and maceration of the cerebellum. (Figure 6)

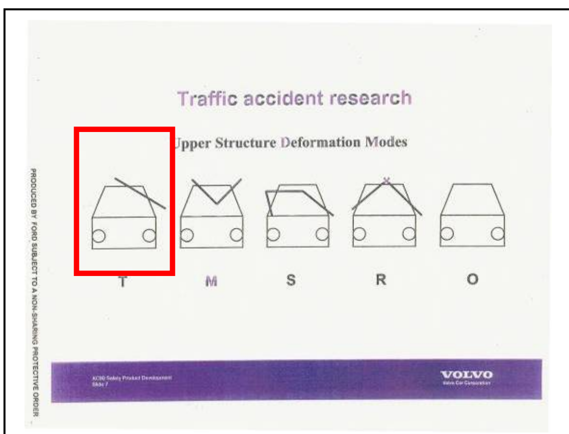


FIGURE 3

FIGURE 4
Restrained driver's skull cleaved by dynamic, vertical crush of roof rail/window frame

FIGURE 5
Blood and tissue noted at scene on interior and exterior of intruding window frame/roof rail

FIGURE 6
Regular borders of skin wounds consistent with cleavage by "sharp" metal of window frame/roof rail.

CASE STUDY 2: Basilar Skull Fracture, Closed

A restrained female driver (21 yrs, 66 inches, 136 lb) of a 2000 Ford Explorer rolled under highway conditions, passenger-side leading a total of four complete rolls. During the rollover, her head was partially ejected out the driver's side window and was positioned below the driver's side roof rail when the structure crushed downward and inboard. The impact, which was just left of the mid-sagittal plane resulted in a degloving, scalp laceration, linear skull fracture and underlying fatal brain injury. During the collision, a minimum of 7 inches of slack was introduced dynamically into the driver's belt restraint system, due to B-pillar collapse and retractor unlocking during the rollover. This slack, in turn, passed into the driver's lap belt with concomitant loss of effective restraint. She was found dead at the scene.

FIGURE 7
2000 Ford Explorer at Final Rest

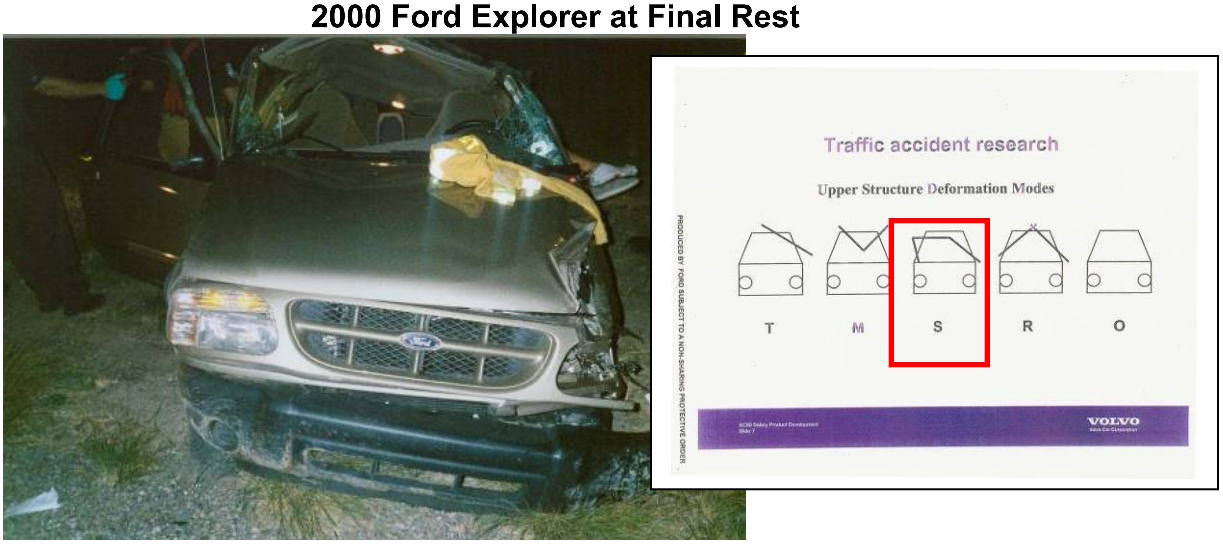


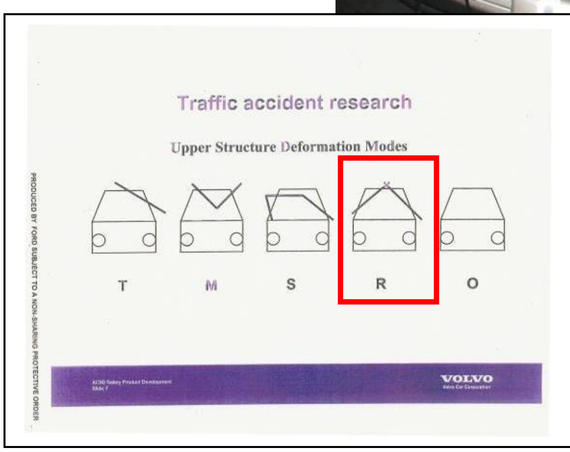
FIGURE 8
Deceased college (honors) student in post-crash, final rest position
(Note adequacy of post-crash headroom, as defined by NPRM.)

In addition to load rate, published cadaver tests conclusively demonstrate that the “end conditions” or (in the real world) the degree to which the head is free to move out of the way of an intruding roof has a fundamental influence on whether or not serious neck injury occurs. Nightingale et al. (1991) have reported that when the upper cervical spine is free to move through its full physiologic range of motion (i.e. “unconstrained”, no injury results when loaded under quasi-static loading conditions. By constraining or trapping the upper spine or head in one plane (i.e. “rotational constraint”) a specific catastrophic injury was produced (bilateral facet dislocation, BFD, also known as bilateral locked facets.) Full constraint (i.e. upper cervical spine and/or head unable to move in any dimension; fully trapped) resulted in compression fractures of the vertebral bodies. Real world rollover cases often demonstrate a combination of these injury modes due to the three dimensional, dynamic nature of the roof-to-head contacts. Neither one-sided nor two-sided static tests can reproduce this injury-producing environment found in real world rollovers. Such crash scenarios are exemplified by the following case studies.

CASE STUDY 3: Wedge Compression Fracture with Bilateral Locked Facets

A restrained female driver (40 yrs, 64 inches, 200 lb) of a 1998 Kia Sportage lost control of her vehicle under icy road conditions and rolled two times. During the rollover, the driver's side of the vehicle sustained roof damage and the driver's head was trapped underneath the deforming window frame. (Figure 9) She sustained multiple spinal fractures, including C7-T1 bilateral locked facets with anterior wedging, resulting in permanent quadriplegia.

FIGURE 9
1998 Kia Sportage



The restrained driver's head was trapped in the deforming window frame as evidenced by the concavity in the upper frame from occupant loading.

The entrapment of an occupant's head, resulting in a catastrophic cervical spine injury was predicted in the dynamic rollover tests of the 1998-1999 Ford Explorers, which was described in a previous submission to the roof crush docket. (Docket No. NHTSA-1999-5572-120) Referring to Figure 10, the video clips of the first 1000 milliseconds from test B190043 demonstrate:

- Internal camera views of Autoliv Test B190043, which have been time-synchronized with the passenger dummy M_y (head flexion: chin-to-chest) neck load cell.

- A continuous deformation wave progressing from the first ground strike (driver's roof rail), across the roof, and onto the passenger's side roof rail (indicated by the red box in the data graph).

- During the first ground strike, the driver's side roof rail strikes the driver dummy's head; however, the dummy head is unconstrained and no injurious neck loads were recorded.

- In contrast, the passenger dummy head is "trapped" between the deformation wave progressing toward the passenger side, as well as, the collapse of the A-pillar on the passenger side. Based on the dummy sensor data, a catastrophic neck injury was predicted at 764 ms (Table 3).

- At all times during the first 1000 ms, the dummies' heads were in contact with the roof. Restated, the dummies exhibited ZERO HEADROOM beginning with the roof-to-ground contact; however, injurious neck loads were not recorded until significant roof crush occurred.

- Dynamic roof crush (not simple head contact) was the direct cause of the injurious neck load recorded in the passenger dummy.

- The far side occupant dummy repeatedly demonstrated injurious neck loads in all three Autoliv tests, whereas the near-side occupant escaped likely injury during the first ground strike event.

- The timing of roof crush that Ford represented to NHTSA in this same test (Docket No. NHTSA-1999-5572-75) is also illustrated in the passenger neck load data trace. This misrepresentation of data was reported to NHTSA previously (NHTSA-1999-5572-120). To date, no specific factual clarification or rebuttal has been filed by Ford Motor Company to the public docket in response to this author's criticism of Ford's actions in this regard.

The far side occupant dummy consistently predicted injurious neck loads in the Autoliv tests, which occurred simultaneous to observed roof crush.

TABLE 3
(From NHTSA-1999-5572-120)

MAGNITUDES OF *LOCAL* AND *ABSOLUTE* MAXIMUM NECK LOADS
(During Time Interval of Continuous Roof-to-Ground Contact)

TEST PARAMETER	DRIVER			PASSENGER		
	B190042	B190043	B180220	B190042	B190043	B180220
Max Peak F_z (N)[3]	-958	-1960	-1920	-5933[1]	-3245	None[2]
Local Peak(s), F_z	-200	-295	-223	-361	-50	200-260
Max Peak M_y (Nm)	58	110	93	304	177	261
Local Peak(s), M_y	2	11	2-54	12-22	20-24	10
Max Peak M_x (Nm)	-106	-124	-167	68	98	41
Local Peak(s), M_x	-11 to-18	n/a	-20 to-46	9	12	19-21

[1] Magnitudes in red indicate these test parameters exceed the known tolerance of the human cervical spine (see Section 1.3.1 in NHTSA-1999-5572-120)

[2] In Test 180220, no absolute maximum F_z was identified as all peak neck compression loads were within the range of 200-260 N. Notably, the M_y values in B180220 and B190043 exceeds the known tolerance value, even though no driver side M_y injurious loads were recorded for any of the tests, though the Fz loads were as high as approximately 2000 N.

[3] F_z was measured at the dummy upper neck load cell; M_y and M_x measured at the lower load cell.

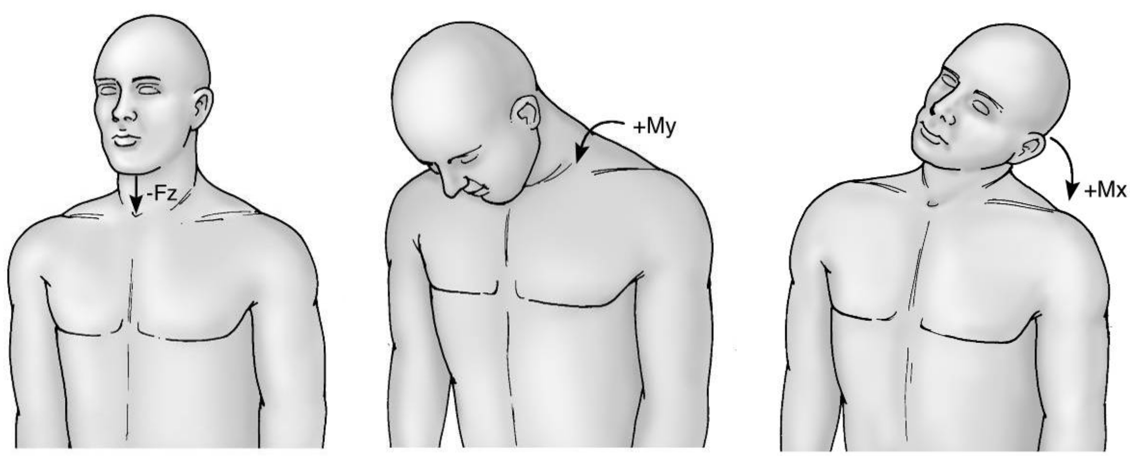
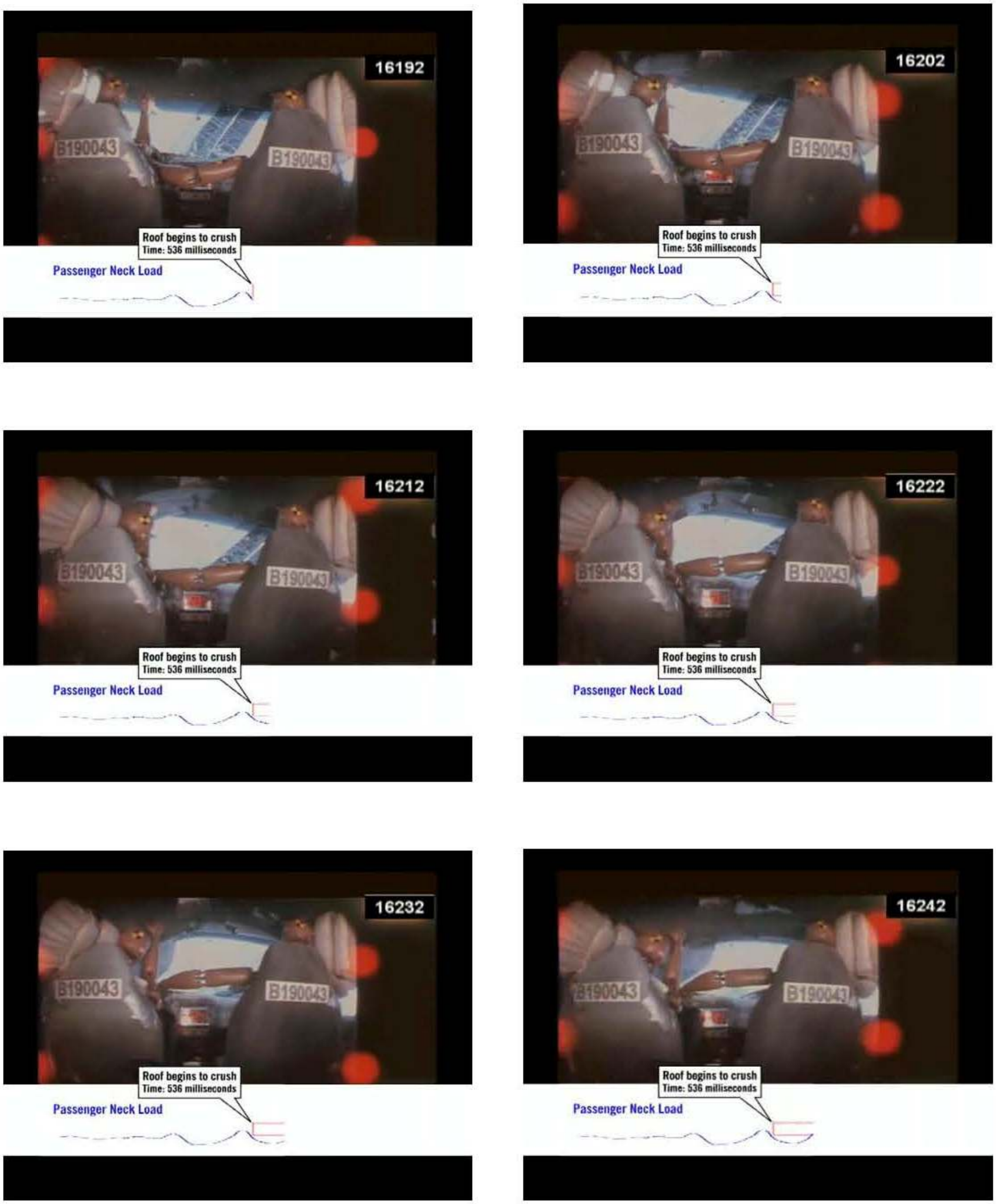


FIGURE 10
Observable Roof Crush and Passenger Neck Load



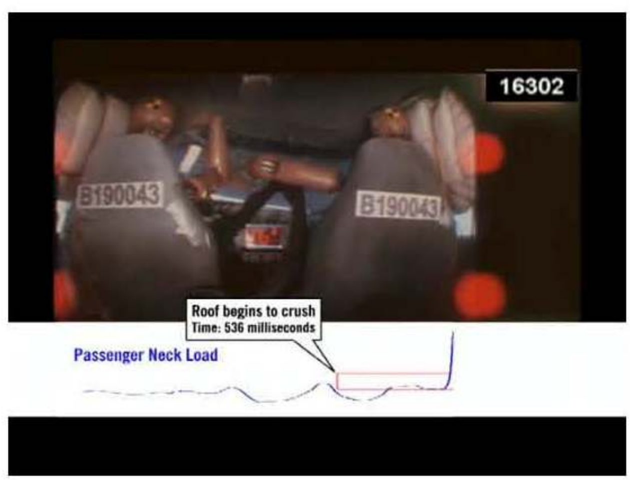

16252
B190043
B190043
Roof begins to crush
Time: 536 milliseconds
Passenger Neck Load

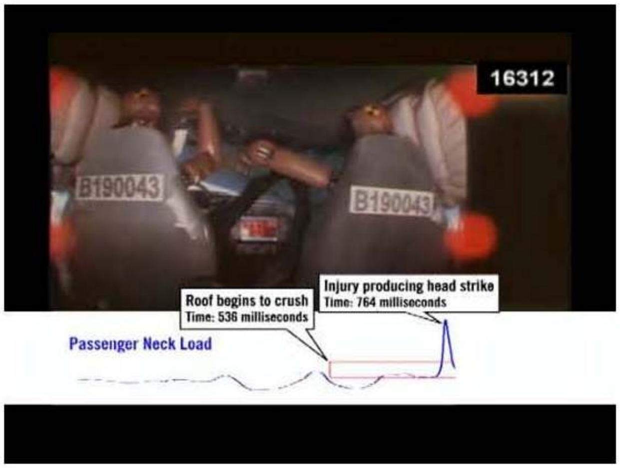

16262
Roof begins to crush
Time: 536 milliseconds
Passenger Neck Load

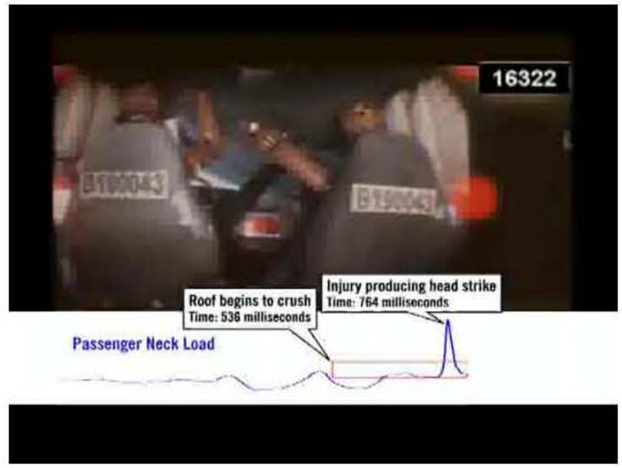

16272
B190043
B190043
Roof begins to crush
Time: 536 milliseconds
Passenger Neck Load


16282
B190043
B190043
Roof begins to crush
Time: 536 milliseconds
Passenger Neck Load

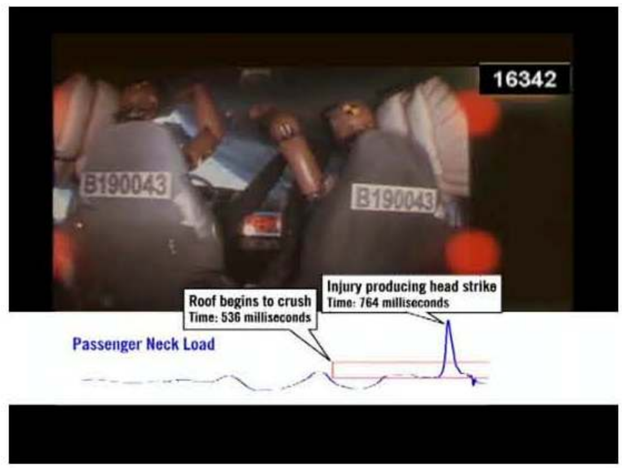

16292
B190043
B190043
Roof begins to crush
Time: 536 milliseconds
Passenger Neck Load

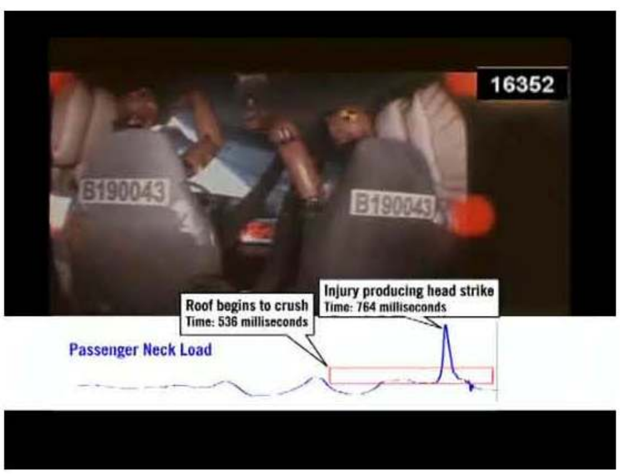

16302
B190043
B190043
Roof begins to crush
Time: 536 milliseconds
Passenger Neck Load

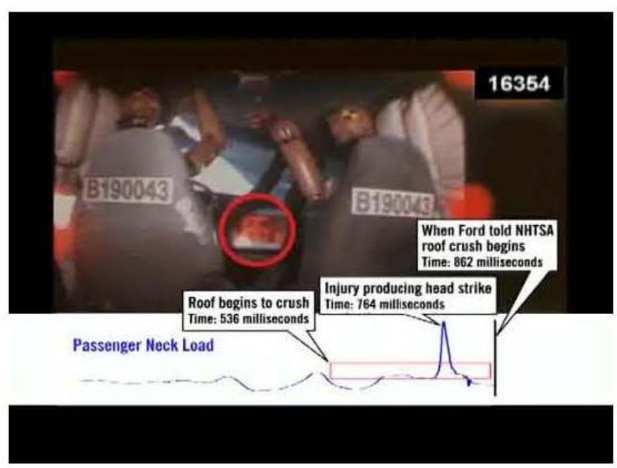

16312
B190043
B190043
Injury producing head strike
Time: 764 milliseconds
Roof begins to crush
Time: 536 milliseconds
Passenger Neck Load


16322
Injury producing head strike
Time: 764 milliseconds
Roof begins to crush
Time: 536 milliseconds
Passenger Neck Load


16332
B190043
B190043
Injury producing head strike
Time: 764 milliseconds
Roof begins to crush
Time: 536 milliseconds
Passenger Neck Load


16342
B190043
B190043
Injury producing head strike
Time: 764 milliseconds
Roof begins to crush
Time: 536 milliseconds
Passenger Neck Load

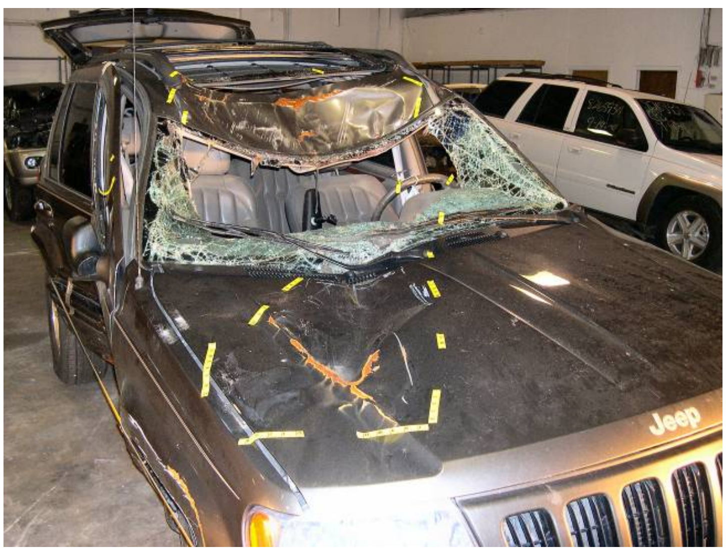

16352
B190043
B190043
Injury producing head strike
Time: 764 milliseconds
Roof begins to crush
Time: 536 milliseconds
Passenger Neck Load

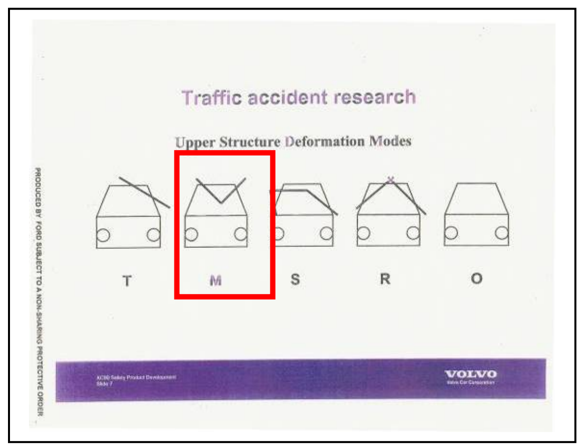

16354
When Ford told NHTSA
roof crush begins
Time: 862 milliseconds
Injury producing head strike
Time: 764 milliseconds
Roof begins to crush
Time: 536 milliseconds
Passenger Neck Load

CASE STUDY 4: Unilateral Facet Dislocation

A 1999 Jeep Cherokee rolled onto its driver's side after being struck in the passenger side by a Ford Taurus which was driven through a red traffic light in an intersection. The Jeep then slid on the road (on its driver's side). The restrained, male driver (49 yrs, 68 inches, 168 lbs) did not lose consciousness during this initial ground impact. Instead, he reportedly used his left arm as a brace to keep his head from being partially ejected and sliding on the road. While in this "braced" position, the roof of the Jeep impacted a parked minivan, causing the roof to intrude into the driver's occupant survival space. The deforming roof contacted the right side of the driver's head, causing it to rotate counterclockwise (i.e. toward his left shoulder) beyond its physiologic limits. (Figure 11) The resulting injury was a right, unilateral locked facet at the level of C4-C5 with concomitant spinal cord injury and quadriplegia.

FIGURE 11
1999 Jeep Cherokee SUV





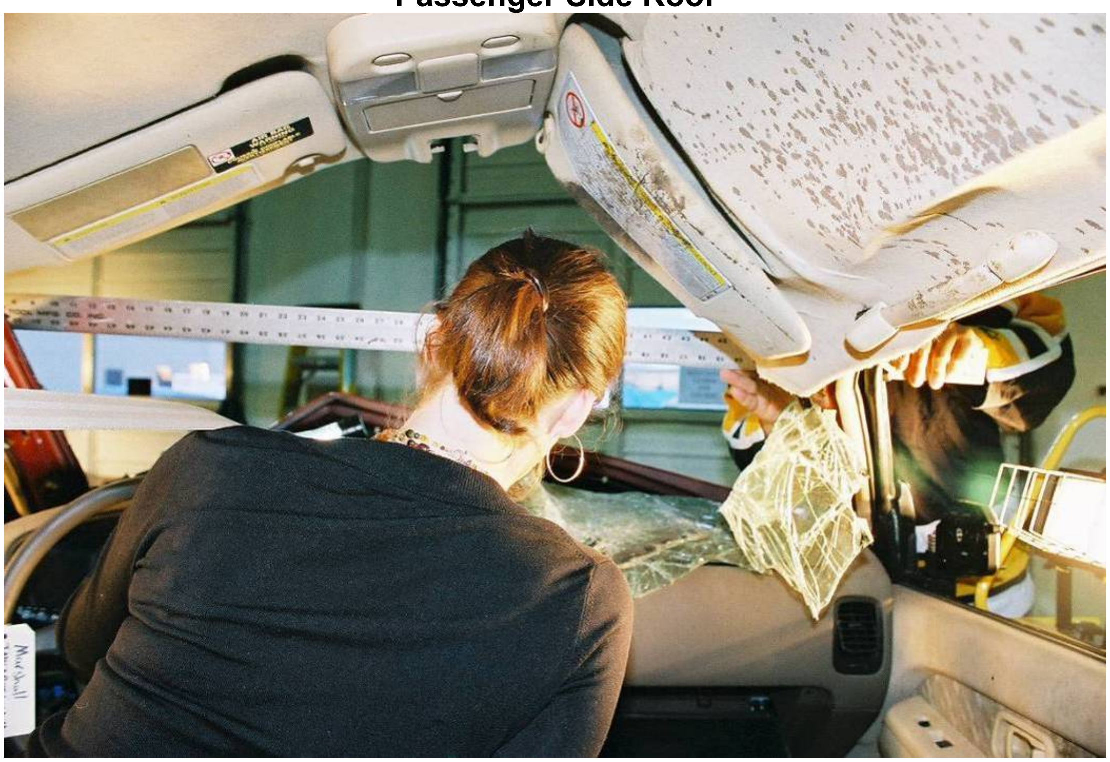
CASE STUDY 5: Facet Fractures and Traumatic Brain Injury

A restrained female driver (37 yrs, 66 inches, 135 lb) was driving a 1997 Nissan Pathfinder 4-door SUV when it drifted off the pavement to the left. The driver steered back to the right to bring the vehicle back onto the roadway. The vehicle began to yaw and subsequently rolled over (Figure 12). She sustained bilateral fractured facets and a large right frontal parieto-temporal epidural hematoma with underlying depressed skull fracture.

FIGURE 12
1997 Nissan Pathfinder

FIGURE 13
Concave Impression in the Driver's Side Roof Liner with Blood Stain
(Photographic perspective taken from the rear occupant compartment)

FIGURE 14
a. Belted Driver Rolls out of Shoulder Belt Toward Intruding Passenger Side Roof



b. Blood and hair located on passenger side sun visor from driver head contact

2. The argument advanced by the auto industry and supported by NHTSA that the existing FMVSS 208 dynamic dolly rollover test is neither repeatable nor reliable is scientifically false and misleading.

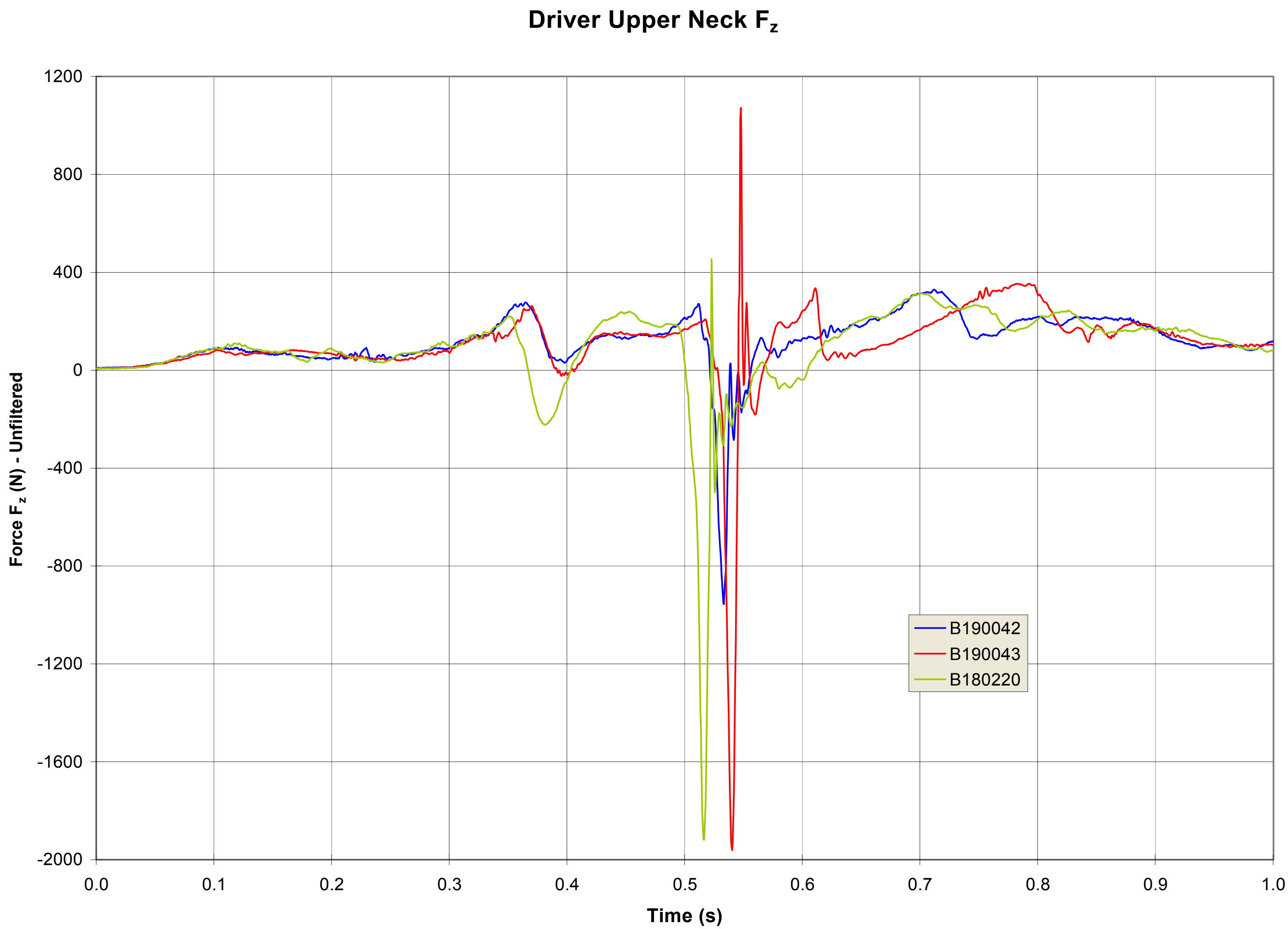
The auto industry for years has sharply criticized the FMVSS 208 dolly rollover test methodology for its alleged lack of reliability and/or repeatability. Such conclusions, however, suffer from a fundamental scientific flaw in methodology. The proper frame of reference for assessing the validity of a dynamic test aimed at occupant protection in rollovers is, of course, **THE OCCUPANT**. Instead, the auto industry has obscured the injury-predictive opportunities inherent in the existing J2114 rollover tests by focusing inappropriately on test-to-test differences, which are largely scientifically irrelevant with respect to injury causation (e.g. number of ground contacts, number of rolls, pitch, roll and yaw angles during the roll).

Rollover tests of the Ford Explorer conducted by Autoliv[5] demonstrate the existing FMVSS 208 dynamic, dolly rollover test to be reliable when viewed from a scientifically valid, occupant protection (vehicle-based) frame of reference. The Autoliv dolly rollover results were remarkably similar in predicting the time of occurrence of absolute maximum neck loads in four different tests. In these tests, the driver was the near-side occupant and the passenger was the far-side occupant in these driver-side leading rollover tests.

- The absolute maximum value for Upper Neck F_z occurred in all three tests at 530 ± 15 ms for the driver dummy (Figure 15a) and 730 ± 15 ms for the passenger dummy (Figure 15b).

[5] Docket No. NHTSA-1999-5572-120

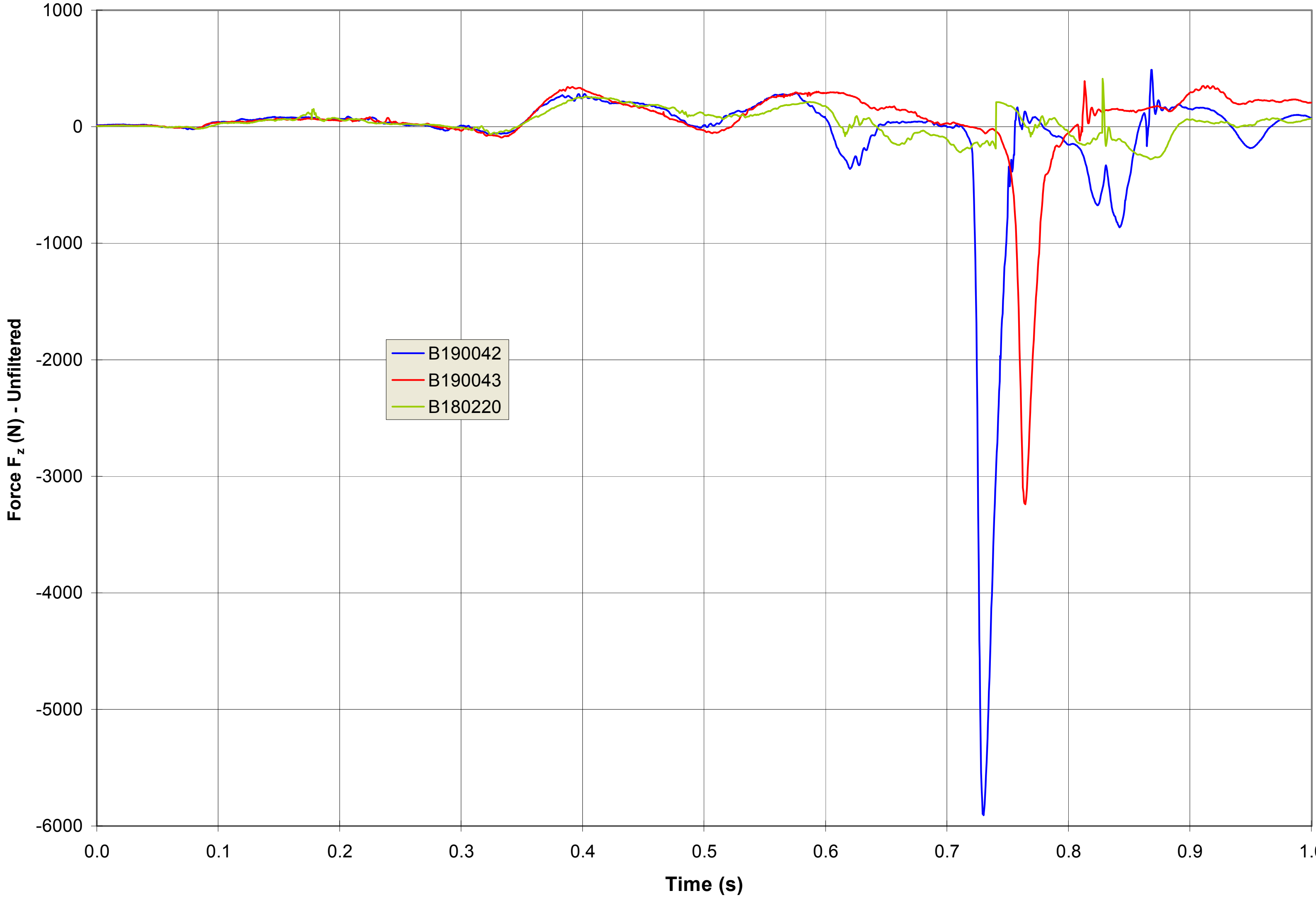
FIGURE 15a



Driver Upper Neck F_z
1200
800
400
0
-400
-800
-1200
-1600
-2000
Force F_z (N) - Unfiltered
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Time (s)
B190042
B190043
B180220

FIGURE 15b

Passenger Upper Neck F_z



- The absolute maximum value for Lower Neck M_y occurred in all three tests at 530 ± 18 ms for the driver dummy (Figure 16a) and 750 ± 21 ms for the passenger dummy (Figure 16b).

FIGURE 16a

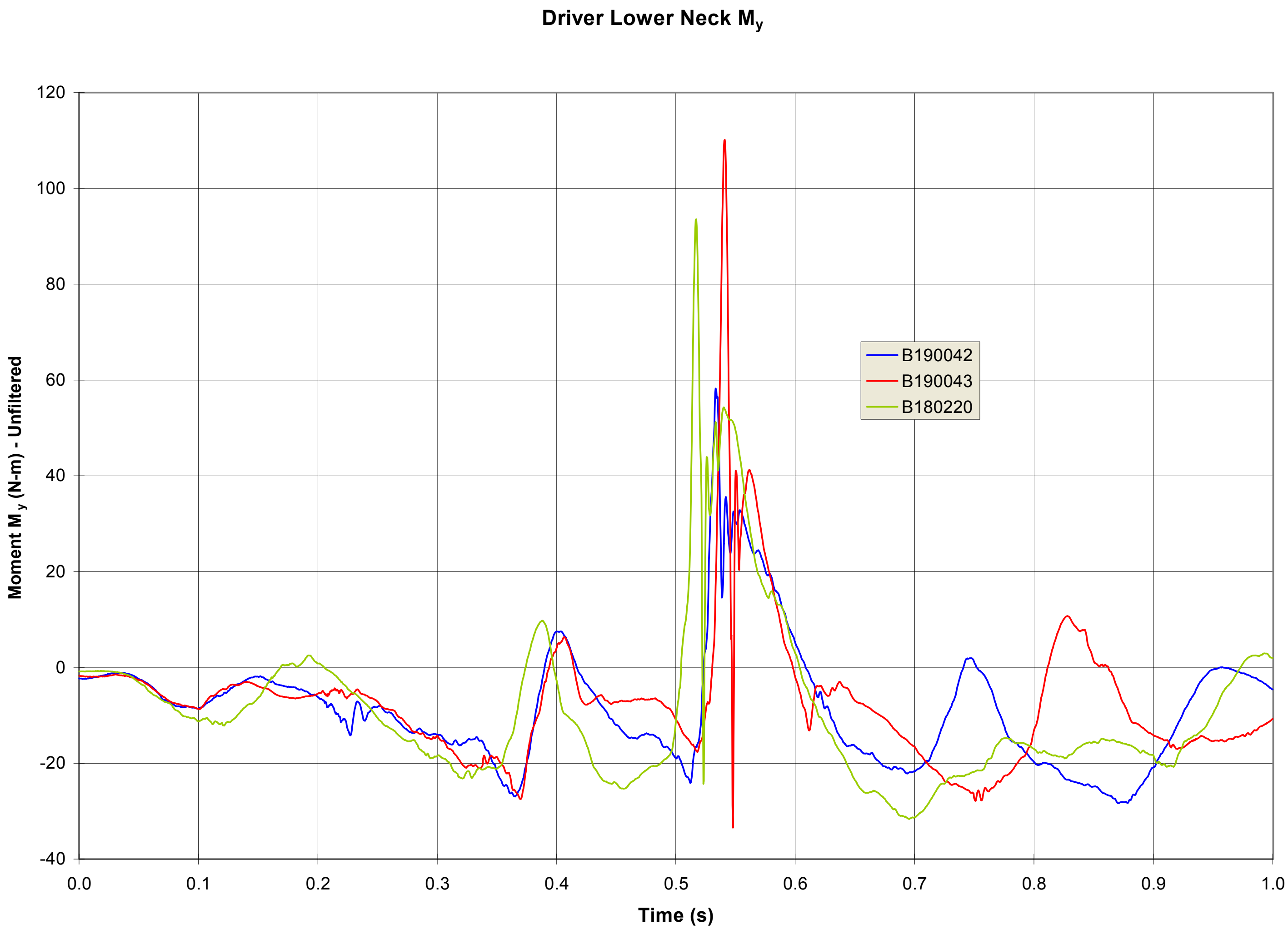
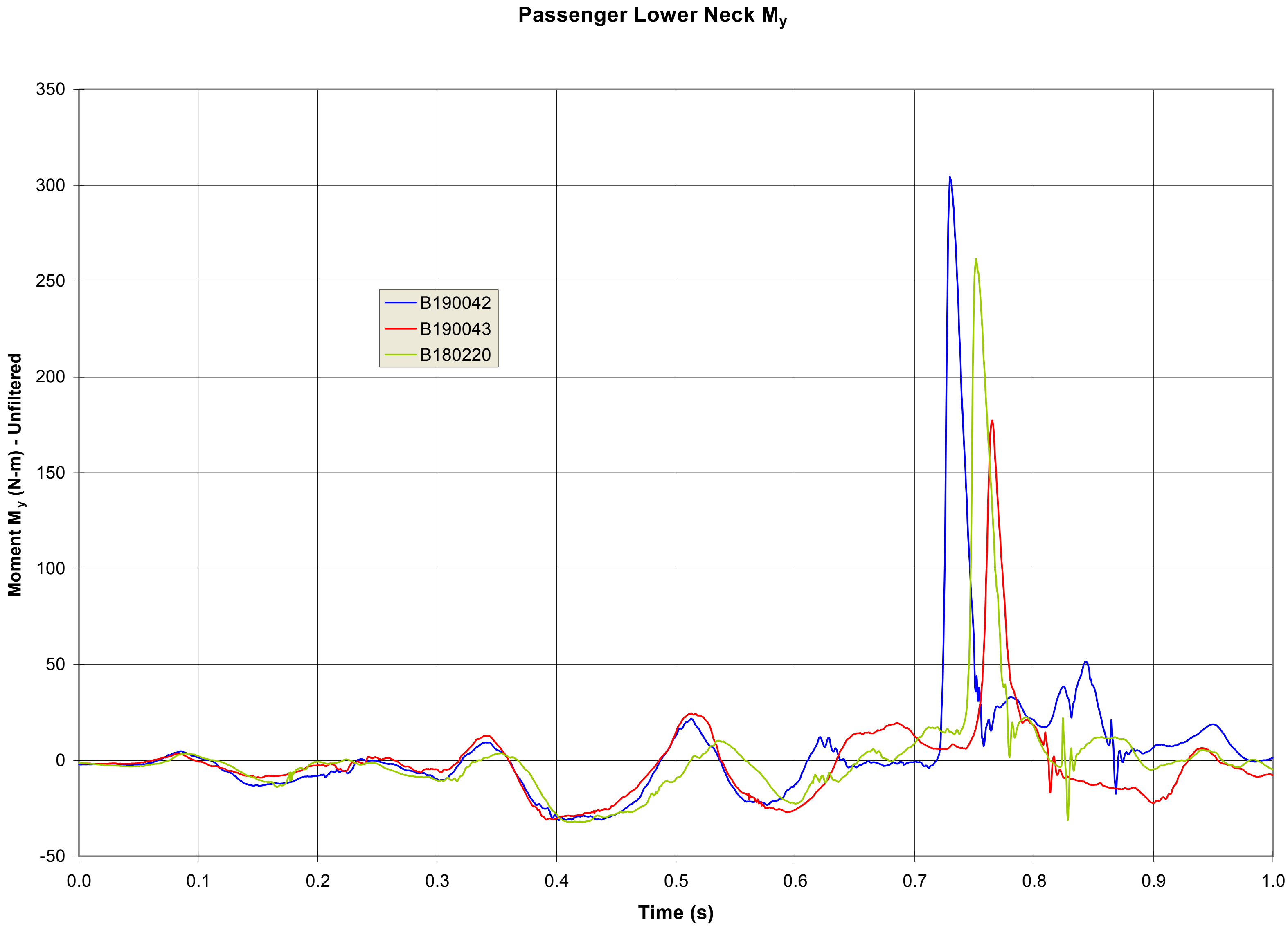


FIGURE 16b


Passenger Lower Neck M_y
Moment M_y (N-m) - Unfiltered
Time (s)
B190042
B190043
B180220
350
300
250
200
150
100
50
0
-50
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

- The absolute maximum value for Lower Neck M_x (ear-to-shoulder lateral bending) occurred in all three tests at 530 ± 18 ms for the driver dummy (Figure 17a) and 770 ± 13 ms for the passenger dummy (Figure 17b).

FIGURE 17a

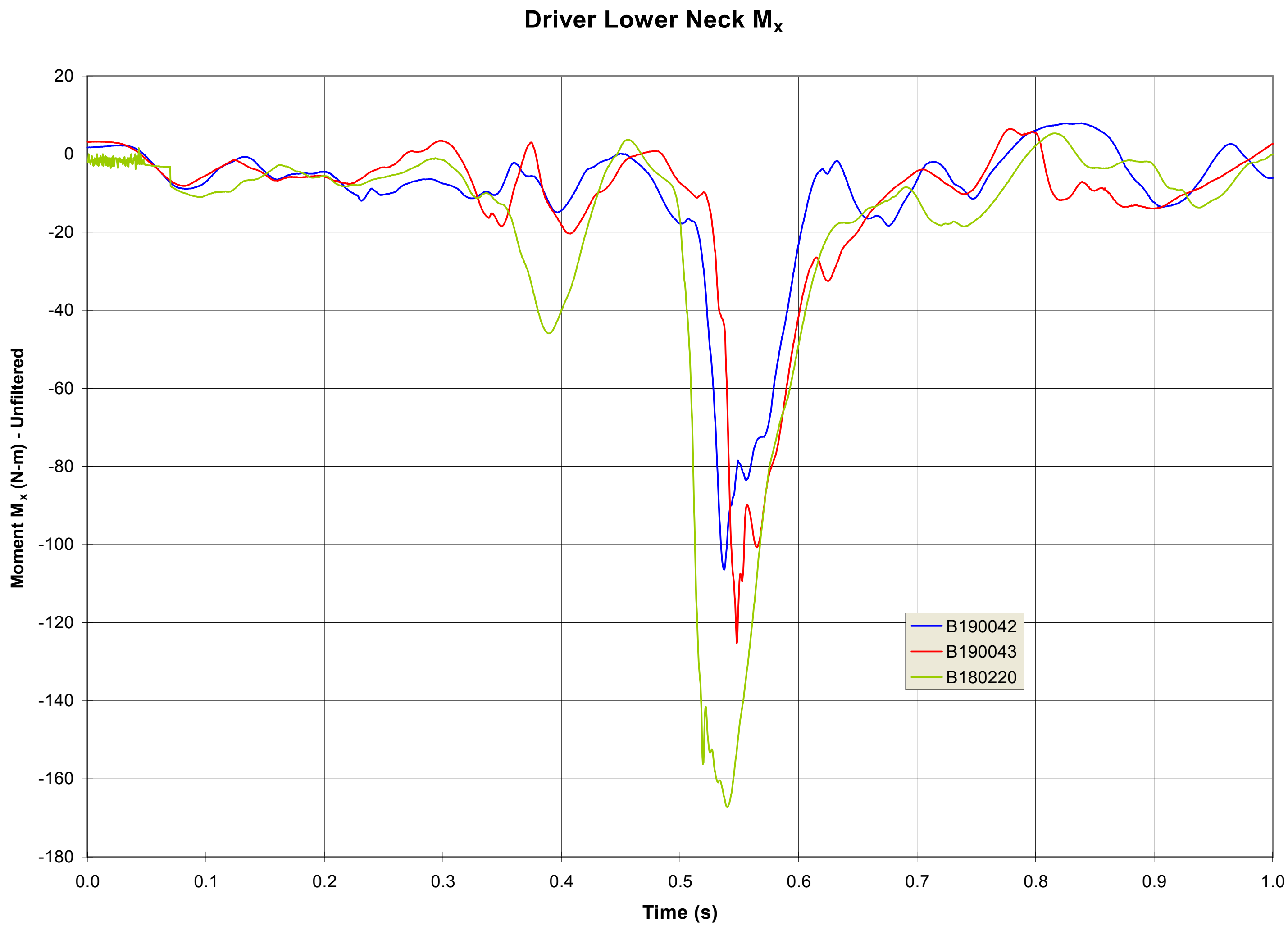
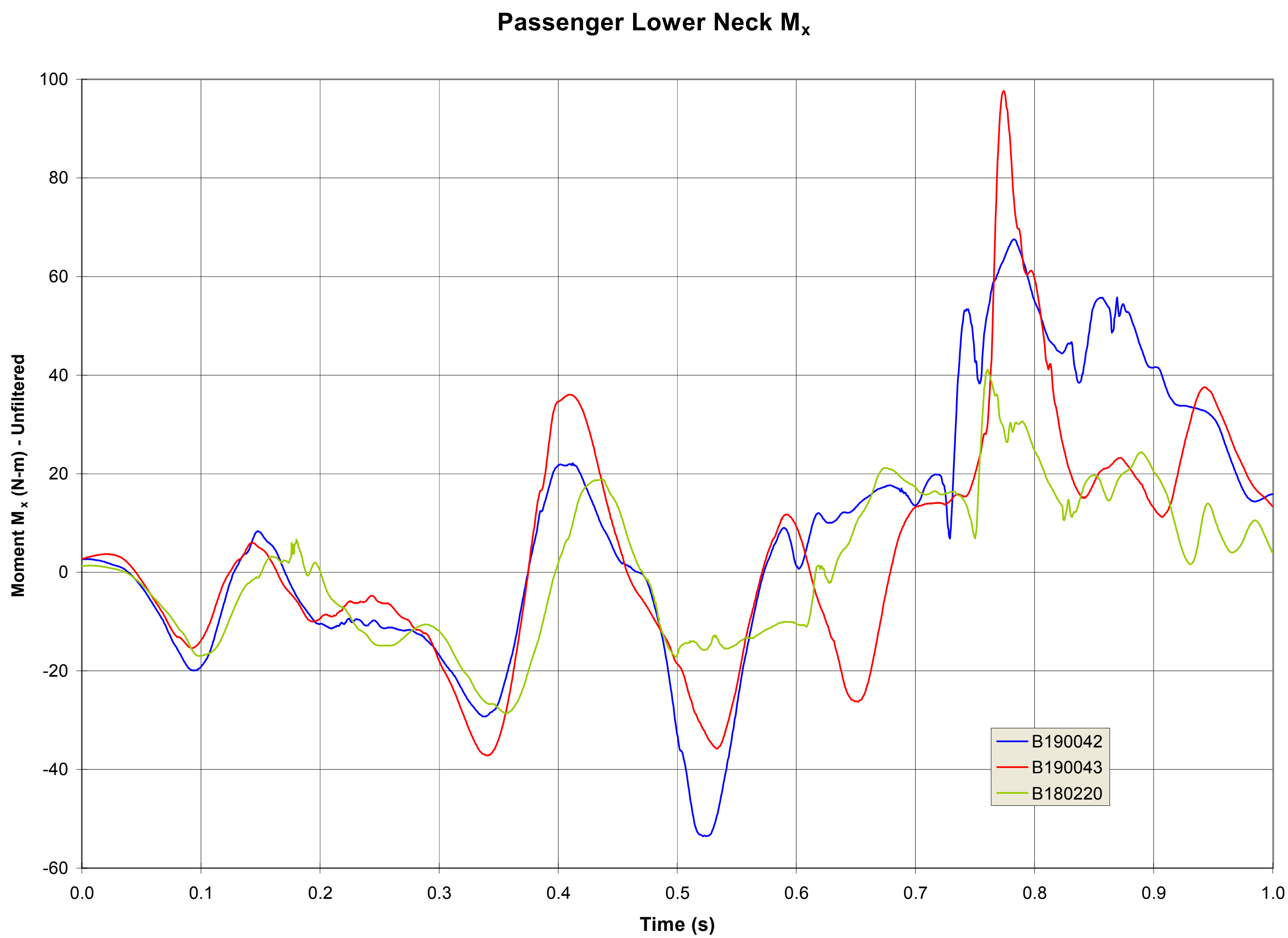


FIGURE 17b


Passenger Lower Neck M_x
100
80
60
40
20
0
-20
-40
-60
Moment M_x (N-m) - Unfiltered
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Time (s)
B190042
B190043
B180220

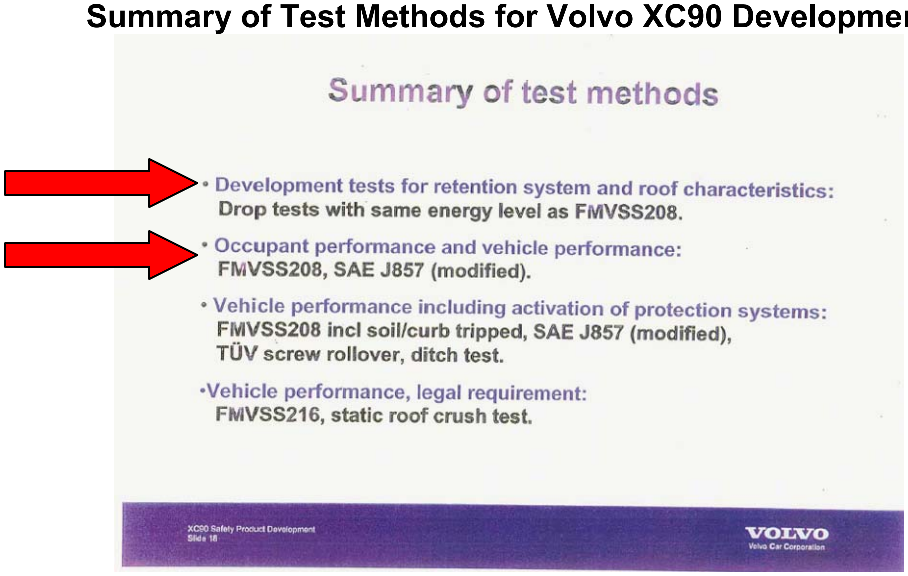
These small variations in time of occurrence of roof/pillar deformation and peak neck loads are particularly remarkable given, that

- The data came from 6 different dummies and 3 different (Ford Explorer) vehicles tested on 3 different days
- The differences in the time of occurrence of the peak neck loads was ≤20 ms in an overall time interval of 1000 ms
- Each 1000 ms time interval included either a sampling rate of 20,000 data points (B190043 and B190042) or 12,500 (B180220)

At least one manufacturer, Volvo, has put into practice the FMVSS 208 dolly rollover test as the best available test for assessing the entire occupant protection *system* in rollovers. (Figure 18) Volvo refers to the existing FMVSS 216 test as a "component" test, necessary for legal compliance. In contrast, the test for occupant protection used by Volvo is the existing FMVSS 208 dolly rollover test protocol and (modified) SAE J857 test.

Occupant injury in rollovers is a function of load magnitude, direction, duration and rate, as well as degree of head entrapment and head initial position, which may only be assessed in the three-dimensional test environment of a full-scale dynamic rollover test. It is important to realize that a dynamic roof energy calculation to transform a static test into a dynamically equivalent result is limited by the type of dynamic test utilized for comparison. As reported by Rains and Voorhis (1998), the dynamic transformation was based upon drop tests of the same vehicle. It is well established that drop tests cannot and do not predict occupant injury in a rollover environment. Rather, a drop test only provides another means of a "component" test for "retention system and roof characteristics" (Figure 18) in a single ground contact. The drop test is a well-accepted method routinely used to evaluate weak points in the roof structure and proposed alternative methods of strengthening those weak areas.

FIGURE 18
Summary of Test Methods for Volvo XC90 Development

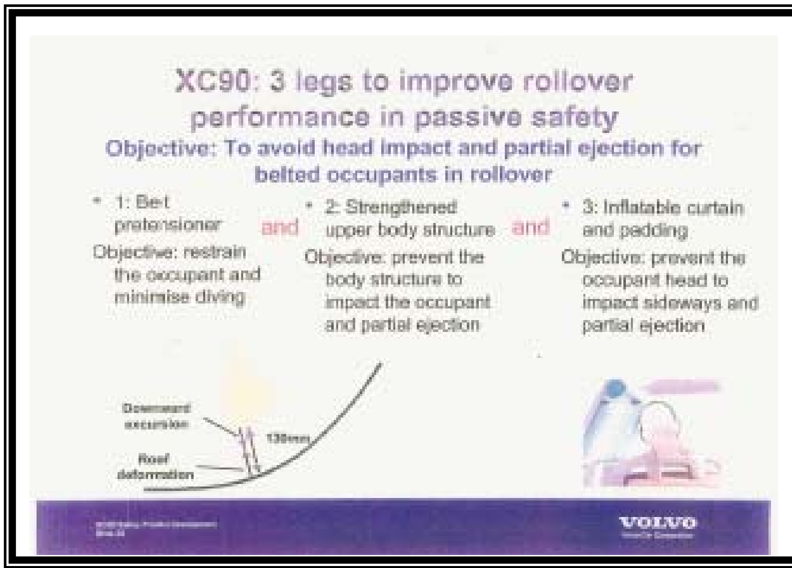


> 3. Rollover occupant protection is not and cannot be predicted by a singular, static “**component**” test, which is proposed in the NPRM; a test of the entire occupant protection **system** is required.

From a rollover occupant protection standpoint, a comprehensive occupant protection system must include three key components of passive safety, all of which was put into practice by Volvo in the development of its XC-90 SUV in the mid to late 1990’s (Figure 19).

> (1) A safety belt system that provides and maintains appropriate fit, comfort, and proper coupling of the occupant to the vehicle seat, with appropriate energy attenuation capability for the foreseeable range of occupant sizes,
>
> (2) A body structure that maintains the occupant survival space (Franchini, 1969) and does not pose an unreasonable risk of injury to belted occupants, and
>
> (3) Effective restraint and structural integrity so as to prevent lateral head impacts and partial ejection through side window portals.

FIGURE 19



Such enhanced passive safety is clearly achievable and has been for many years, at least from a technological standpoint. Enhanced safety may be achieved using a variety of features, including belt pretensioners, strengthened upper body structures, integrated safety belt systems that incorporate pretensioning systems, roll bars, extended head restraints, and inflatable side air curtains, coupled with energy-attenuation padding to roof rail and pillar structures. These features, both independently and in combination with each other, have been evaluated, studied, tested, and, in some cases, even patented for use in providing protection to consumers involved in rollover crashes.

In simple terms, a meaningful upgrade to the FMVSS 216 standard must include a **systems approach** to rollover occupant safety. The protection necessary is a combination of measures, which cannot be judged in isolation. For instance, a vehicle with an inherently weak roof, but a superb, state of the art safety belt system, is not reasonably safe because belted occupants are exposed to an unreasonable risk of injury from an intruding roof. Likewise, for example, a vehicle design that incorporates a reasonably safe roof design, but is equipped with a safety belt that allows the occupant to move outside the occupant compartment is not a reasonably safe design. Thus, federal standards aimed at providing scientifically valid rollover occupant protection must avoid isolated component tests and instead, necessarily test the overall vehicle ***system*** design in a simulated real-world, dynamic rollover environment.

4. Post-test headroom does not reflect dynamic headroom observed in dolly rollover and real world crashes; therefore, it is scientifically baseless to use post-test headroom as a sole measure of occupant injury potential in rollovers.

A recent NHTSA study of 1997-2001 NASS data[6] concluded that a rollover occupant with negative post-crash headroom[7] had 5 times the odds of a particular level of injury severity than an occupant with positive post-crash headroom. The study limitations were carefully documented and the statistical analysis was robust in comparison to other industry-sponsored studies of NASS rollover data related to FMVSS 216 published in the rollover docket[8].

The stated purpose of the NHTSA study was “to determine whether there is a statistically significant relationship between the severity of head, neck, and face injuries due to roof contact during rollovers and the headroom remaining over the occupant after the crash.” Importantly, the authors cautioned against unintended uses of the study related to rulemaking.

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[6] Docket No. NHTSA-2005-22143-52

[7] Post crash headroom was defined as the vertical distance from the top of the occupant’s head to the bottom of the roof liner over the occupant’s head after a relevant rollover. Thus “negative post-crash headroom reflects roof crush below the original position of the top of the occupant’s head.

[8] Refer to Docket No. NHTSA-1999-5572; Submissions by JP Research, Inc./Padmanaban et al.

"The study is not intended to make specific recommendations for changes to Federal Motor Vehicle Safety Standard (FMVSS) No. 216, "Roof Crush Resistance," nor is it intended to calculate benefits from any such change. Instead, the conclusions in this study are meant to provide a basis and rationale for further analysis."

From a biomechanical engineering perspective, **post-crash headroom is a *necessary, but insufficient* measure of occupant protection in rollovers**. To use the variable as a sole measure of occupant protection potential in rollovers is scientifically baseless. The case for using a full scale dolly rollover test with dynamic monitoring of restrained crash dummy head and neck sensors has been made in this report and previously (Docket No. NHTSA-1999-5572-120). The points listed below provide further bases for rejecting the current NHTSA proposal to use post-test headroom in a static FMVSS 216 test as the sole predictor of occupant injury in rollover crashes.

1. **Post-crash** headroom as measured in real world rollover crashes is very different in magnitude and final profile than **post-test** headroom as proposed within the "upgraded" static test of FMVSS 216 NPRM.
2. **Post-crash** headroom as measured in dolly rollover tests is very different in magnitude and final profile than **post-test** headroom as proposed within the static test of FMVSS 216 NPRM.
   - In two out of three dolly rollover tests of the Ford Explorer conducted by Autoliv, post-crash vertical headroom actually EXCEEDED the initial headroom, even though catastrophic neck injuries were predicted in all three of the far-side (passenger) crash dummies earlier in each dolly rollover test. (Table 4).

TABLE 4
Autoliv Rollover Tests of Ford Explorer
(Source: Docket No. NHTSA-1999-5572-120)

Test	**Driver Head to Roof (Using only z-component from ref. data)**	**Passenger Head to Roof (Using only z-component from ref. data)**
B180220	212mm (8.3in) Δ 27.3mm (1.1in)	210 mm (8.3in) Δ 22.8mm (0.9in)
B190042	149mm (5.9in) Δ -31mm (-1.22in)	151mm (5.94in) Δ -53.5mm (-2.11in)
B190043	444mm (17.5in) Δ 201mm (7.9in)	333mm (13.1in) Δ 94.7mm (3.73in)

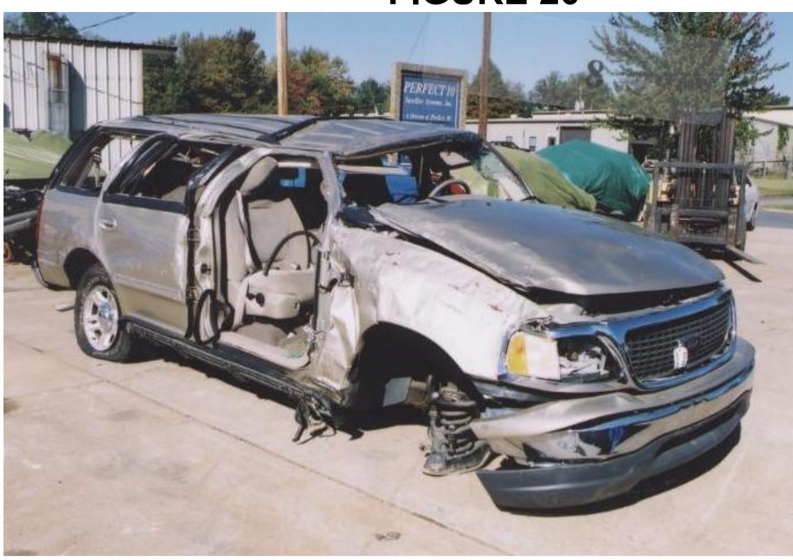
The Autoliv FMVSS 208 dolly rollover tests, the scientific literature regarding dynamic human injury tolerance, and finally, the case studies presented in this report document the scientific invalidity of post-(static) test headroom as the sole means of rollover occupant injury prediction.

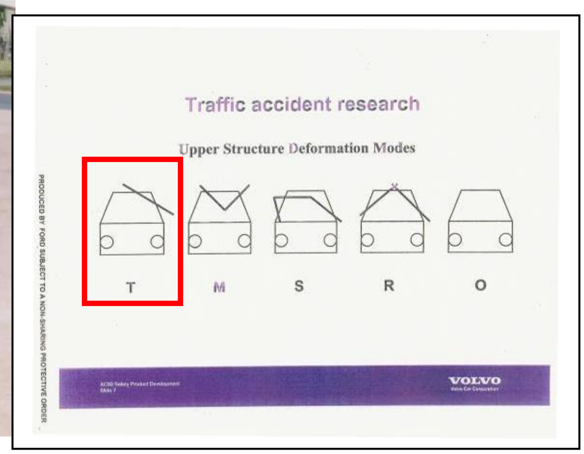
5. Significant lateral roof crush, which often exposes a restrained occupant to serious head impacts with the ground, is not considered in the NPRM.

The NPRM appears to arbitrarily choose to only consider vertical intrusion as a measure of occupant safety, which is a significant omission. Lateral roof intrusion, as observed in Case Study No. 6, can expose an otherwise properly restrained occupant to partial ejection with catastrophic injury or death.

CASE STUDY 6: Fatal Head Injury due to Lateral Roof Deformation

FIGURE 20





A restrained adult male was driving a 2000 Ford Expedition on a two-lane highway, accompanied by his wife and 2 children (seated in back). All occupants were wearing the available safety belt systems. The rear of the vehicle was loaded with luggage. The weather was clear and the road surface was dry. As they traveled down the highway, the Expedition was involved in a loss of control event that resulted in a single vehicle, on-road rollover. The Expedition rolled and came to rest wheels down. The right front passenger was found dead at the scene, still restrained in her lap and shoulder belt. (Figure 20-21) Lateral roof crush opened an ejection portal above her head and she died from head–to-ground contact. (Figure 22)

FIGURE 21
Restrained RF Passenger Dead at the Scene

FIGURE 22
Surrogate demonstrates partial head ejection of front seat passenger

CASE STUDY 7: Bilateral Locked Facets

A properly restrained driver (30 yrs, 74 inches, 180 lbs) was the sole occupant of a 2002 Ford Escape SUV, driving on a four-lane divided highway in the New England area. Snow and slush were noted to be present on the road. His SUV slid off the left side of the roadway into the median and rolled over twice, coming to rest wheels down. (Figure 23) The driver was found alert, but unable to exit the vehicle. EMS personnel cut his seatbelt, the vehicle roof and the driver's door during the extrication process. The air bags did not deploy.

The 2002 Ford Escape slid approximately 50 feet off the left side of the roadway into the median, and at approximately 31 mph, rolled a total of 2 rolls, driver-side-leading over a distance of 70 feet. The rollover occurred over a 3.1 second interval, resulting in an average roll rate of 232 degrees/second for this low speed rollover event. As the rollover occurred, the driver initially moved to his left, against the driver's door, remaining in that position, essentially upright, until the Escape's roof structure collapsed into his occupant survival space, crushing the driver's roof rail both inboard and downward. Violent contact was made between the driver's head and the buckling roof. The dynamically deforming roof drove his head into hyperflexion resulting in C6-7 bilateral locked facets with significant anterior dislocation and resultant quadriplegia.

FIGURE 23

2002 Ford Escape after 2-roll, low-speed rollover accident

6. An important, vulnerable population is completely neglected in the NHTSA "Comprehensive Rollover Plan" and the NPRM: rear occupants, including children restrained in aftermarket child restraints as well as OEM belt restraints.

Rollover crashes result in the highest rate for MAIS 3+ injury to children aged 4-12 years old in car crashes (Figure 24), yet absolutely no provision has been made to protect these most vulnerable passengers in the current NPRM. Many adult women, including those presented in case studies in this report, are in the same stature range as 11-12 year old youth. (Table 5). No dynamic rear seat occupant protection criteria is provided for this population in any part of the NPRM or the entire FMVSS. NHTSA, however, as well as the auto industry and every child advocacy group in the U.S., continue to advise parents and caregivers to restrain all children aged 12 years and under in the back seat.

FIGURE 24

Rate (#/1000) of seriously injured MAIS 3+ children aged 4-12 years involved in crashes for front and second row seating.
(Parenteau and Viano, 2003)

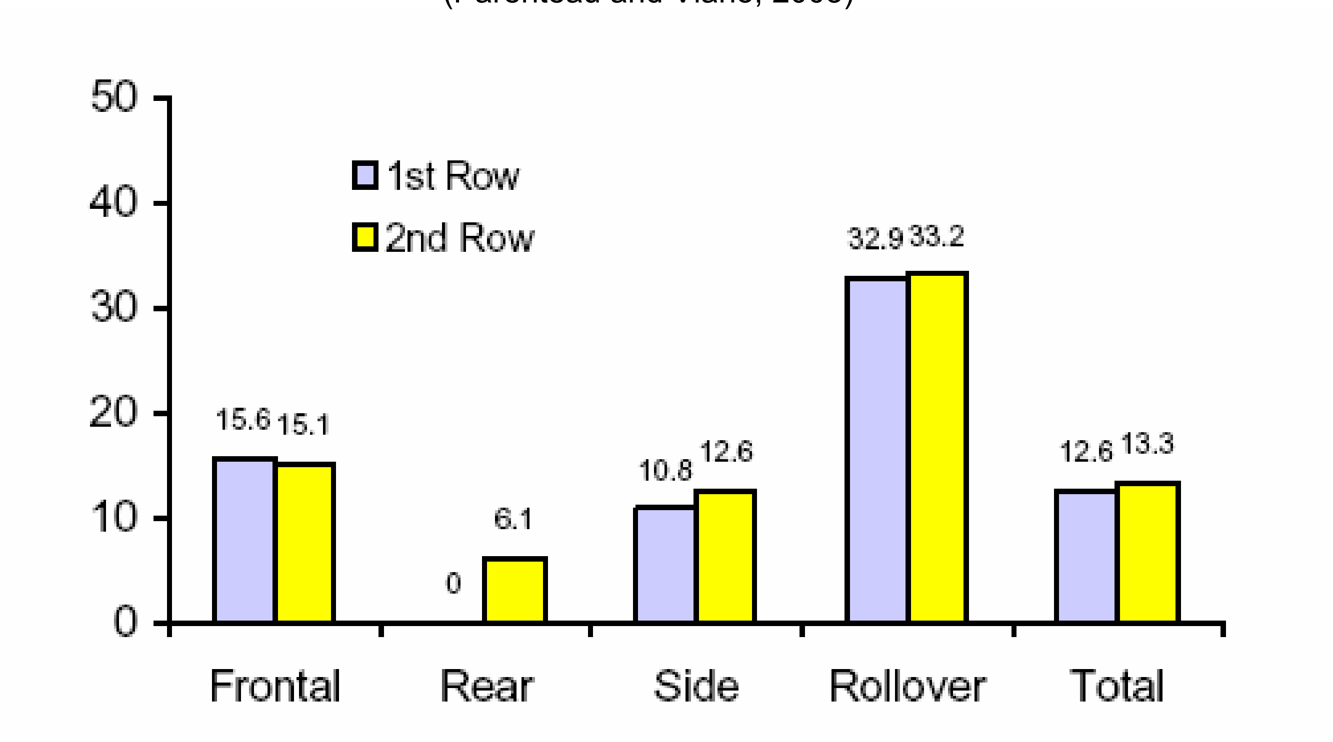


Table 5 also demonstrates examples of adults (male and female) who are properly restrained front seat occupants; however, their stature is significantly less than the 50^{th} percentile male crash dummy proposed in the current NPRM.

TABLE 5

Case Study No.	Injured Occupant Sex/Age	Injured Occupant Stature	Stature Compared to 50th Percentile Male Dummy[1] (175.3 cm; 69 in)	Comparable Anthropometry Table Age Range[2]	Minimum Stature	5th Percentile	50th Percentile	95th Percentile	Max Stature
1	Female 37 yrs	158.8 cm (62.5 in)	**16.5 cm (6.5 in)**	9.5 – 10.5 yrs	120.1 cm	127.0 cm	137.3 cm	147.8 cm	159.0 cm
2	Female 21 yrs	167.6 cm (66.0 in)	**7.7 cm (3.0 in)**	11.5 – 12.5 yrs	133.3 cm	137.3 cm	149.3 cm	159.9 cm	169.0 cm
3	Female 40 yrs	162.6 cm (64.0 in)	**12.7 cm (5 in)**	11.5 – 12.5 yrs	133.3 cm	137.3 cm	149.3 cm	159.9 cm	169.0 cm
4	Male 49 yrs	172.7 cm (68.0 in)	**2.6 cm (1.0 in)**	12.5 – 13.5 yrs	136.4 cm	142.1 cm	153.4 cm	169.5 cm	179.8 cm
5	Female 37 yrs	167.6 cm (66.0 in)	**7.7 cm (3.0 in)**	11.5 – 12.5 yrs	133.3 cm	137.3 cm	149.3 cm	159.9 cm	169.0 cm
6	Female 41 yrs	160.0 cm (63.0 in)	**15.3 cm (6.0 in)**	10.5 – 11.5 yrs	122.0 cm	133.0 cm	144.0 cm	156.3 cm	161.1 cm
7	Male 30 yrs	188 cm (74 in)	**12.7 cm (5.0 in)**	15.5 – 16.5 yrs	147.3 cm	161.1 cm	174.6 cm	185.2 cm	188.3 cm
8	Female 5 yrs	91.4 cm (36 in)	**83.9 cm (33 in)**	2.0 – 3.5 yrs	83.8 cm	85.1 cm	92.0 cm	99.4 cm	105.9 cm
9	Female 8 yrs	142.2 cm (56 in)	**33.1 cm (13.0 in)**	8.5 – 9.5 yrs	117.8 cm	124.1 cm	132.3 cm	142.2 cm	150.3 cm
10	Female 5 yrs	109.2 (43 in)	**66.1 cm (26.0 in)**	3.5 – 4.5 yrs	91.1 cm	93.9 cm	101.7 cm	108.7 cm	114.1 cm

Notes:

1. FMVSS 216 NPRM proposes post-test vertical headroom measurement relative to seated height of 50th percentile male dummy
2. The youngest age range that includes the injured occupant's stature according to SAE Special Publication SP-450; "Anthropometry of Infants, Children, and Youths to Age 18 for Product Safety Design"

FIGURE 25
NHTSA Advertisement Placed in Popular Women's Magazine (October, 2005)

In October 2005, NHTSA placed an advertisement in "O" magazine suggesting that booster seats are a panacea for child protection, "In the car, his mommy put him in a booster seat and he lived happily ever after." Unfortunately, booster seats, particularly belt positioning booster seats perform poorly in rollover crashes with high likelihood of child ejections. In the present NPRM, NHTSA also excluded all fully or partially ejected occupants from their analysis, making an erroneous assumption that ejected occupants are all unrestrained. The following three case studies illustrate the consequences of NHTSA's tragic omission of child protection in its "comprehensive" rollover plan.

CASE STUDY 8: Fatal Ejection of Child in Booster Seat

FIGURE 26
1996 Isuzu Trooper

A 1996 Isuzu Trooper (Figure 26) was on a highway in the southern US, when the tread came off the left rear tire. The driver lost control of the vehicle and it rolled, coming to rest wheels up.

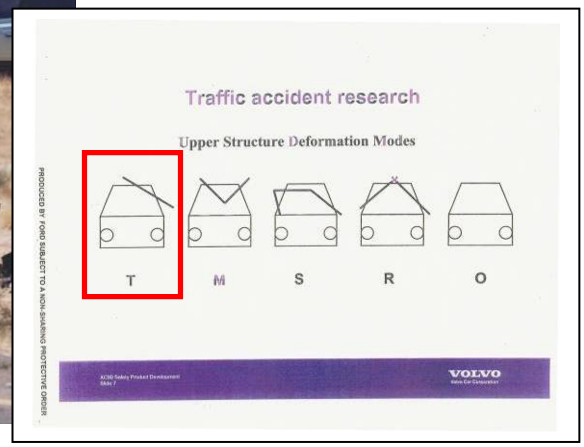
During the crash, a female child (5 yrs, 36 inches, 65 lb) was ejected out of her belt positioning booster seat, through the left rear window and was crushed by the overturning sport utility vehicle (Figure 27a,b). She died of “massive blunt force trauma,” including basilar skull fracture with massive bruising and trauma to right side of face.

FIGURE 27

a. Five Year Old Child Ejected From Belt Positioning Booster Seat

b. Belt positioning booster seat used to restrain the child, according to vehicle and booster seat manufacturer's instructions

CASE STUDY 9: Catastrophic Brain Injury of Restrained Child in Rear Seat



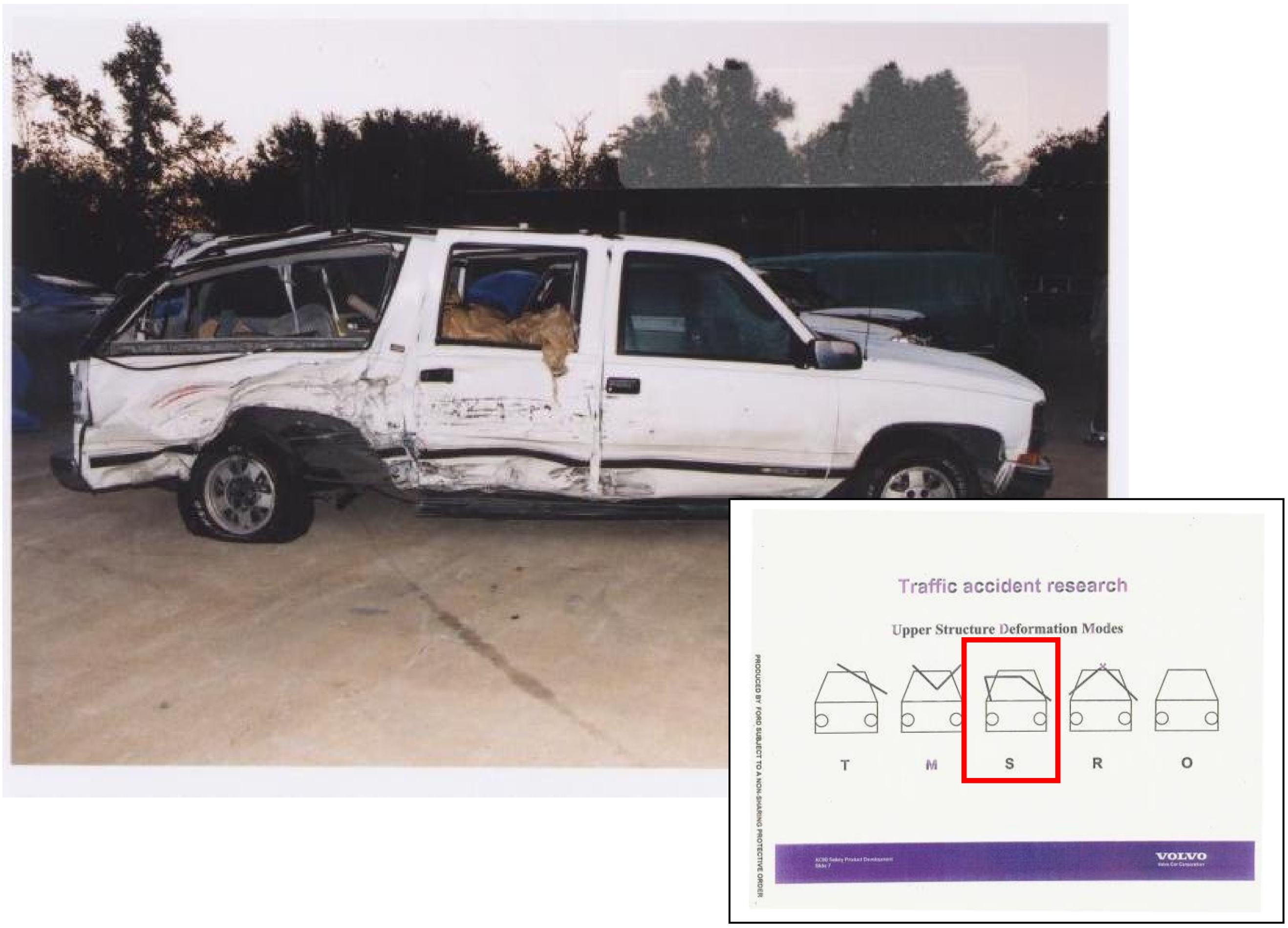
A woman driving her 1997 Chevrolet Suburban, with her husband, mother-in-law and four children, were traveling down a four-lane divided highway, at about 65mph. As it traveled, the right rear tire of the Suburban experienced tread separation, causing it to go flat. The driver applied the brakes and attempted to maintain control. She lost control of the Suburban; it traveled into the grassy median where it rolled. The Suburban came to rest wheels down in the median. A female child (8 yrs, 56 inches, 110 lbs) was the properly lap-shoulder restrained passenger seated directly behind the driver. During the rollover crash, her torso rolled out of her shoulder belt and the left frontal aspect of her head violently impacted the unpadded forward window frame/B-pillar structure. (Figure 26) She sustained a depressed skull fracture in the frontal bone as well as a significant basilar skull fracture, with catastrophic brain injury.

FIGURE 26

Head Contact for left, second row occupant of Suburban

CASE STUDY 10: Fatal Ejection of Child Properly Restrained in Aftermarket Child Seat

FIGURE 27
1994 Chevrolet Suburban



A woman was driving her 1994 Chevrolet Suburban (Figure 27) on a highway in the southern US. Her five-year-old twin girls were riding with her, in the back seat of the Suburban. Both girls were properly restrained in Ascend SE Century child seats. As they proceeded through an intersection, a pickup truck did not stop at a posted stop sign and impacted the Suburban on the right passenger side. The impact to the Suburban caused the SUV to yaw clockwise and ultimately roll over, coming to final rest off road, on the driver's side of the vehicle. During the crash, the right rear child occupant (5 yrs, 43", 46 lb) was ejected from the Suburban and came to rest with the top of her head partially underneath the vehicle. All occupants of the Suburban received non-disabling injuries with the exception of the ejected young girl seated in the right side, middle row of the Chevrolet Suburban. She sustained a massive skull fracture (MAIS 5) and was pronounced dead, just over one hour post-crash. (Figure 28)

FIGURE 28
5 Year Old Girl Fatally Ejected from 5-Point Harness Booster Seat in 1994 Chevrolet Suburban Rollover

CONCLUSIONS

An upgrade of the existing FMVSS 216 is long overdue; however, the current NPRM, if implemented as a final rule, will provide no additional protection to rollover occupants. A static, component test, irrespective of the test variables, simply has no scientific basis in injury prevention within the rollover crash environment. The arguments against more meaningful upgrades citing a likelihood of upsetting the balance within NHTSA's comprehensive rollover plan are disingenuous. How can a plan be considered comprehensive when absolutely no protection is offered to anyone in the back seat(s) of vehicles, particularly children? NHTSA has seemingly arbitrarily ignored the fact that the rate of MAIS 3+ injuries for children aged 4-12 years is 2-3 times higher in rollover crashes compared to all other crash modes!

This report supplements my research group's prior submission to Docket No. NHTSA-2005-5572-120, which is included by reference. NHTSA has full access to ALL of the Volvo XC90 development documents, which are protected against public view. I have included only limited images of those which are unprotected. The Volvo XC90 documents contain a clear, proven road map to what is required to provide meaningful, comprehensive rollover protection. Anything less is a reckless, arbitrary abdication of the agency's responsibility to protect the motoring public.

BIBLIOGRAPHY

1. Franchini,E. “The Crash Survival Space” SAE 690005, 1969
2. Myers, B.S. and Nightingale,R.W. “The Dynamics of Head and Neck Impact and Its Role in Injury Prevention and the Complex Clinical Presentation of Cervical Spine Injury.” IRCOBI Conference Proceedings No. 1997-13-0001– Hannover, September 1997.
3. Myers, B.N., Nightingale, R.W. “Review: The Dynamics of Near Vertex Head Impact and its Role in Injury Prevention and the Complex Clinical Presentation of Basicranial and Cervical Spine Injury.” *J. Crash Prevention and Injury Control* 1(1)67-82, 1999
4. Nightingale, R.M., McElhaney, J.H., Camacho, D.L., Kleinberger, M; Winkelstein, B.A., Myers, B.S. (1997). "The Dynamic Responses of the Cervical Spine: Buckling, End Conditions, and Tolerance in Compressive Impacts." SAE 973344.
5. Nightingale, R.W., J.H. McElhaney, W.J. Richardson, B.S. Myers “Dynamic Responses of the Head and Cerivcal Spine to Axial Impact Loading” *J. of Biomechanics* 29(3) pp 307-318,1996
6. Nightingale, R.W., J.H. McElhaney, W.J. Richardson, T. Best, B.S. Myers “Experimental Impact Injury to the Cervical Spine: Relating Motion of the head and the Mechanism of Injury” *J. of Bone and Joint Surgery* 78(3), 412-421,1996
7. Nightingale, R.W., B.J. Doherty, Myers, B.S., J.H. McElhaney and W.J. Richardson,. “The Influence of End Condition on Human Cervical Spine Injury Mechanism”. Proc 35th Stapp Car Crash Conference. 1991. San Diego, Ca: Society of Automotive Engineers, Inc. p 391-399 SAE 912915
8. Padmanaban, J.,Moffatt, E., Marth, D. “Factors Influencing the Likelihood of Fatality and Serious/Fatal Injury in Single Vehicle Rollover Crashes.” Submission to Docket No. NHTSA-1999-5572-70. February 7, 2004
9. Parenteau, C. and Viano, D.C. “Field Data Analysis of Rear Occupant Injuries Part II: Children, Toddlers and Infants.” SAE 2003-01-0154.
10. Pintar, F., Sances, Jr., Yoganadan, N., Reinartz, J., Maiman, D., Keun Suh, J., Unger, G., Cusick, J., Larson, S., “ Biodynamics of the Total Human Cadaveric Spine” SAE 902309
11. Pintar, F., Yoganadan, N., Voo, L., Cusick, J., Maiman, D., Sances, Jr., A. “Dynamic Characteristics of the Human Cervical Spine” SAE 952722
12. Rains and Van Voorhis, “Quasi Static and Dynamic Roof Crush Testing,” DOT/NHTSA VRTC-82-0197/VRTC-86-0391; 1998
13. Yoganadan,N., Pintar, F., Sances, Jr., A., Reinartz, J., Larson, S., “Strength and Kinematic Response of Dynamic Cervical Spine Injuries” Spine 16 (10) 1991

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The technical assistance of Mr. Donald Burke, III and Ms. Kathryn Mergl in the preparation of this report is deeply appreciated. Deepest sympathy is expressed to the individuals and families of those individuals cited in the case studies who were needlessly catastrophically injured or killed.