May 11, 2007

Ms. Nicole Nason, Administrator
National Highway Traffic Safety Administration
400 Seventh Street, SW
Washington, DC 20590

Subject: FMVSS 216 Roof Strength NPRM-Docket NHTSA 2005-22143

Dear Ms. Nason:

We respectfully request that you review the attached research paper which we authored and presented to the Society of Automotive Engineers in Detroit on April 16, 2007. The paper is entitled "NHTSA's Benefit Model in the Proposed FMVSS 216 Roof Strength Standard", SAE 2007-01-0373, by Edward Moffatt and Jeya Padmanaban.

Our detailed analysis of the NHTSA's fatality benefit model reveals significant flaws in the assumptions and methodologies. In the enclosed SAE paper, we conclude that the model which NHTSA used to estimate 13-44 lives saved annually, could equally be interpreted to predict zero lives saved annually.

We would welcome the opportunity to discuss our findings with your staff in person, or by telephone.

Sincerely,

Edward A. Moffatt (DK)

Edward A. Moffatt, PhD, PE
Biomech Inc
925-254-2433

Jeya Padmanaban
JP Research
650-559-5999

2007-01-0373

NHTSA's Benefit Model in the Proposed FMVSS 216 Roof Strength Standard

Edward Moffatt
Biomech Inc.

Jeya Padmanaban
JP Research, Inc.

ABSTRACT

As part of a comprehensive plan to reduce the risk of death and serious injury in rollover crashes, NHTSA has proposed upgrading the roof crush resistance standard, FMVSS 216. To evaluate the benefit of this proposal, the agency examined real-world data on injuries and fatalities that would be prevented by the proposed rulemaking. This paper provides a detailed discussion of the statistical and engineering approaches used to derive benefit estimates on fatalities calculated by NHTSA for the proposed upgrade. It concludes the NHTSA estimate of 13-44 lives saved annually is not reliable due to extreme sensitivity of the benefit calculation to the paucity of field data and questionable engineering assumptions.

INTRODUCTION

In 2001, the National Highway Traffic Safety Administration (NHTSA) issued a Request for Comments (1) regarding an upgrade to its Federal Motor Vehicle Safety Standard (FMVSS) on Roof Crush Resistance: FMVSS 216, which has remained essentially unchanged since 1973. In response, it received over 4,300 pages of submissions, with a voluminous amount of data, opinions, and suggestions, many of which were fundamentally contradictory. Upon its review of many of these docket submissions, and utilizing accident data analysis and laboratory testing on the role of roof crush and injury in rollovers, NHTSA presented its plan for the upgraded roof crush resistance standard in the 2005 Notice of Proposed Rule Making (NPRM) (2).

Basically, the proposed new standard would increase the strength of vehicle roofs from the current requirement of 1.5 times the vehicle roof-strength-to-weight ratio within five inches of platen travel to a new requirement of 2.5 times (2.5X) the roof strength-to-weight ratio before the roof contacts the head of a seated crash dummy.

The justification for the NPRM's proposed upgrade to the roof strength standard is NHTSA's estimates of the annual number of fatalities and injuries that would be prevented. In particular, NHTSA has estimated that the new standard would prevent 13 to 44 fatalities each year. The NPRM, together with the subsequent Preliminary Regulatory Impact Analysis (PRIA) (3), presents a comprehensive analysis, which formed the basis of NHTSA's benefit estimates.

This paper provides a detailed discussion of the data and methodology used, and the underlying assumptions made, by NHTSA to derive the fatality benefit estimates.

REVIEW OF THE FATALITY REDUCTION CALCULATION

NHTSA estimates that 13-44 lives will be saved annually by the proposed roof strength standard. The formula by which these estimates are made is never directly provided in the PRIA. However, the formula may be deduced from PRIA Tables IV-6 and IV-10 and the text description of each of the factors in those tables. NHTSA's fatality reduction calculation is based on the following formula (we have expanded the names of each factor for clarity):

$$\text{Predicted Annual Fatality Reduction} = (N * E * F) * C$$

Where:

N = Annual "relevant rollover exposure population" (from weighted NASS data)

E = "Effectiveness rate": percent of fatalities prevented for the "relevant population" due to maintaining positive headroom (91.4%)

F = "Failure rate": percent of vehicle fleet that will require changes to pass the new standard (32.4%)

C = Correction factor for increased future belt use and electronic stability control.

In this paper, the first three factors used in the "fatality reduction" calculation (N, E and F) are discussed in detail, and the influence of each on the sensitivity of the fatality benefit estimate of 13-44 lives saved is explored.

FACTOR 1: N = RELEVANT ROLLOVER EXPOSURE POPULATION

NHTSA used National Automotive Sampling System (NASS) Crashworthiness Data System (CDS) data from 1997-2002 to define the "relevant population". The relevant rollover exposure population included belted, non-ejected front seat occupants in rollovers (with more than 1 quarter turn) with known injury severity[1]. The occupants in the relevant population had NASS-coded "vertical intrusion" over the seating position and head/face/neck injuries from a vertically intruded roof component.

There were 31 NASS/CDS fatal cases that met the relevant population selection criteria, and these 31 cases formed the basis for estimating fatalities prevented. The fatality benefit calculation is highly sensitive to the few NASS cases available and to the weighting assigned to each. In the original 31 fatal cases, 67% of the entire benefit was attributed to just two heavily weighted cases.

Upon selection of the relevant rollover population, NHTSA then used two approaches (Approach A and Approach B) to estimate the number of fatalities that would be prevented annually. Under Approach A, NHTSA estimated that 13 fatalities would be prevented. However, for this approach, NHTSA used occupant height information from the NASS/CDS files, which was available only for four relevant cases, with one case (1997-48-006) accounting for the majority of the estimate. Under approach B, NHTSA expanded the size of the data set by assuming a national distribution of occupant heights instead of the height of the actual occupant in the NASS crash. Under Approach B, NHTSA estimated that 44 fatalities would be prevented. Approach B used 31 relevant fatality cases, but 12 of them accounted for 99% of benefit calculation.

The calculation of benefits in both approaches was based on the predicted change in post-crash headroom due to the proposed standard (3). The fatality reduction benefit attributed to vehicle post-crash headroom was formulated from a recent NHTSA analysis by Austin, et al. (4) that examined the relationship between fatality and what the study defined as "post-crash headroom" (i.e., "the pre-crash space over the occupant's head minus the amount of vertical intrusion of a roof component"). The Austin study found a statistically significant relationship between head/face/neck injury and the presence/absence of post-crash headroom (the validity of which finding is discussed in detail later in this paper).

In both approaches, NHTSA calculated which of the 31 NASS rollovers had "negative post-crash headroom" (the upright headroom of the occupant before the crash, minus the amount of roof crush above the occupant after the crash) and then estimated whether the 2.5X roof strength would have prevented enough roof crush to keep the headroom positive. If the measured post-crash headroom was negative and the calculated (hypothetical) post-crash headroom due to the proposal was positive or zero, then NHTSA assumed that the new standard would be beneficial in reducing fatality and, hence, included that NASS/CDS case to estimate benefits.

Examination of the 12 NASS Cases Used in Approach B

We made a detailed review of the original NASS case files for those determining 12 cases. The reviews showed that eight of these are not reliable indicators of the proposed benefits of the new roof standard, often because each was involved in a significant collision prior to the rollover. [See the Appendix for reviews and photos of those eight cases here deemed inappropriate].

If those eight cases are removed, the entire benefit analysis would be based upon only four NASS cases. If all other factors remained the same, removal of those eight cases would reduce the estimated annual lives saved from 13-44 down to 0-20 lives saved.

There are two major concerns about NHTSA's use of this relevant population data. First, the appropriateness of making national benefit estimates based on at most 12 NASS/CDS cases, and more reasonably on only four cases (assuming the eight cases in the Appendix are irrelevant), is questionable. Second, in Approach B the assumed occupant height for the person involved in a crash is based on a national distribution rather than the demographics of actual drivers who get involved in rollovers. For example, NHTSA studies (5) show that young males are over represented in rollover fatalities. In addition, the Austin study itself (4) pointed out that there were few cases of single vehicle rollovers involving older occupants. This raises questions about the validity of using a national distribution of occupant heights to study rollovers.

Discussion of Post-Crash Headroom

NHTSA's benefit estimates are based on its finding that the Austin study identified a statistically significant relationship between head/face/neck injury and the

[1] Data included 1987 and later model-year non-convertible light vehicles and age 13 or older occupants. Fatalities with unknown injury information in NASS/CDS file were excluded. The annual fatality estimates were adjusted using FARS (1997-2002) data. For more detailed descriptions of NHTSA's selection of relevant population, please see the PRIA and NPRM.

presence/absence of post-crash headroom in rollovers. The original Austin study (4) analyzed 773 NASS single-vehicle rollovers from 1997-2001. The study presented simple analyses and multivariate analyses to examine the relationship between head/face/neck injury from roof contact and roof intrusion, occupant height, and post-crash headroom. Post-crash headroom was originally modeled as a continuous variable. The Austin study found that "neither the magnitude of negative or positive headroom appears to have any substantial effect on higher levels of injury severity." However, if the post-crash headroom was modeled simply dichotomously (either negative or positive), then it was found to be a "statistically and substantively significant predictor of injury risk."

Engineering Fallacy of the Post-Crash Headroom Assumption

NHTSA's post-crash headroom assumption raises several critical conceptual issues. The benefit calculations rely upon the concept that a loss in upright headroom below the level of the occupant's head causes injury. The concept of loss of headroom is an inaccurate representation, however, because it fails to acknowledge one of the most important fact about the kinematics of seatbelted occupants in rollovers; that is: a belted occupant in a rollover typically has *zero headroom*, regardless of roof deformation.

Testing demonstrates that, for most adults in most current vehicles, if you simply seatbelt them and invert the vehicle, the excursion allowed by seatbelts and human body compliance will allow their heads to reach the roof without any roof deformation. Numerous authors have addressed the "vertical excursion" expected to belted occupants in rollovers. Rains et al. of NHTSA (6) conducted both static and impact excursion measurements of seatbelted dummies and found typical excursions of about three inches. Moffatt and James (7) reviewed the static excursion tests published in six other papers (Bahling et al. (8), Arndt et al. (9), Herbst et al. (10), James et al. (11), Moffatt et al. (12), and Meyer et al. (13)) and noted seatbelted human excursions ranging from three to nine inches, with the average about four to five inches. The PRIA lists the pre-crash upright headroom recorded by Consumers Union, which is typically about four inches. The conclusion from the Rains (6) and other inversion tests is, then, that for most of the 31 NASS case vehicles, if the occupants were simply belted and inverted, it is likely their heads would reach the roof in the absence of any roof crush. Moffatt and James (7) included a collage of photographs from 14 inversion tests with a variety of vehicles and occupant sizes in all of which the belted occupant head was against the roof.

The use of the upright head position of an occupant to represent the inverted dynamic head position during a rollover is not borne out by any excursion testing or rollover crash testing with which the authors of this paper are familiar. If it was NHTSA's intention to imply that a belted occupant's head would not reach the roof in the absence of roof deformation, then we respectfully request clarification of the basis for this critical assumption.

Statistical Fallacy of the Post-Crash Headroom Assumption

The ordinal logistic regression analyses performed by NHTSA (4) were examined in detail. First, data sets for the same years of NASS/CDS (1997-2001) were developed with same selection criteria, and NHTSA's statistical analyses were repeated to reproduce results[2]. Then the following refinements were made to NHTSA's data and methodology:

1. We included additional years of NASS/CDS data (1997-2004);

2. For the dependent variable, we used a dichotomous variable (0 if AIS 0, 1 or 2; and 1 if AIS is 3-6) as opposed to an ordinal variable, and we used a survey logistic regression model; and

3. We obtained vehicle headroom measurements from SAE H61 data files for each make/model, and occupant height and exact vertical roof deformation from the NASS/CDS files.

In addition, vehicle roof strength-to-weight ratios (as measured by FMVSS 216) were included in the data set to examine the relationship between roof strength and head/face/neck injury/fatality.

The following results were observed:

- Our logistic regression models were first run separating the three elements (vehicle headroom, exact roof deformation, and occupant height) that contributed to NHTSA's post-crash headroom variable. When the three variables were separated, only vertical roof deformation was a significant predictor of serious (AIS 3-6) head/face/neck injury in rollovers. Occupant height and vehicle headroom were not statistically significant predictors. We found that the only significant predictors[3] of severe/fatal injury odds included vertical roof deformation, driver age, and number of rolls.

- When the vertical roof deformation variable was replaced by available[4] roof strength-to-weight ratio (as measured by FMVSS 216) in the logistic model, roof strength-to-weight ratio was not found to be a

[2] The authors closely matched the results (coefficients of variables included) of Austin study models.
[3] In the Austin study, age was not a significant predictor of rollover injury.
[4] Roof strength-to-weight ratio data was available for about 400 vehicles in the data set.

statistically significant predictor of odds of serious injury. This means that the relationship between roof deformation and serious injury is due to factors other than vehicle roof strength. Some of these factors include how, when, and where the initial roll energy is dissipated; roll distance combined with topography (long distance on flat desert road versus short distance with change in terrain); and rollover type, arrested rolls versus non-arrested rolls (14).

- Our results demonstrate that the logistic models presented in the Austin study are sensitive to inclusion/exclusion of variables influencing injury severity in rollovers. When small samples are used to build logistic models, it is extremely important to examine the interaction among variables and perform sensitivity analyses to ensure the stability of the regression model and the validity of the conclusions. The Austin study does not report any study of these interactions.

Causation Assumption

A final issue is that the Austin study's analysis fails to address whether the correlation between negative post-crash headroom and injury reflects a causal relationship. This paper addresses that issue in depth in a subsequent section (see CORRELATION OR CAUSATION).

The engineering and statistical fallacies presented in the preceding sections raise serious questions about the validity of NHTSA's conclusions on the importance of post-crash headroom.

FACTOR 2: E = EFFECTIVENESS OF MAINTAINING HEADROOM TO PREVENT FATALITIES

The NPRM presents an "effectiveness" factor that predicts the influence that maintaining post-crash headroom has on preventing fatality. NHTSA calculated an effectiveness rate of 91.4% for preventing fatalities (derived from PRIA Table IV-9).

This high rate of effectiveness for fatalities is an artifact of the very small samples used. As indicated earlier, the fatality estimates were based on 31 fatal cases, out of which only 12 accounted for 99% of the weighted annual estimate. With this small data set our analysis found that the NHTSA's 91.4% estimate has a confidence bound of 70-100%. This means that, if the effectiveness rate was 70%, then the number of lives saved would be 10-34. No acknowledgement of consequences of wide confidence bounds on fatality benefit is made by the NHTSA.

FACTOR 3: F = NUMBER OF VEHICLES WITH UPGRADED ROOFS

The third factor in the benefit calculation estimates that 32.4% of future vehicles will require upgraded roofs. To determine this number, NHTSA performed FMVSS 216 tests on 20 vehicles. Thirteen of the 20 vehicles in these FMVSS 216 tests would have passed the proposed 2.5X roof standard upgrade, because their roof strength reached a level of 250% of vehicle weight prior to the roof displacement making contact with the head position of the dummy. Seven of the vehicles did not reach the 250% proposed standard. The PRIA used the results of these 20 tests to project that, based upon sales figures, 32.4% of the current fleet would not meet the new standard.

The fatality benefit formula is highly sensitive to the 20 vehicles NHTSA selected. A random switch of just one vehicle could have resulted in a five percent difference in the projected pass/fail rate. Most of the vehicles were tested simply because they were already owned by NHTSA from other test programs. No explanation is offered in the PRIA to justify that this self-selection of vehicles is, in fact, a representative sample of vehicles on the road.

NHTSA also used the 20-vehicle test program to analyze how much loss in headroom would have occurred in the 31-vehicle NASS file if those vehicles had passed the proposed 2.5X standard. The NHTSA methodology was as follows:

- The force/displacement curves for the seven current vehicles which failed the proposed 2.5X standard were averaged. This average of the seven vehicles which did not meet the 2.5X standard is called the "baseline."

- The baseline average was then used to project a representative force/deflection curve if the vehicles were strengthened to meet the 2.5X proposal.

- These curves were then integrated to plot the roof crush energy versus roof platen displacement.

- Finally, based upon the average of the energy/deflection results of the tested vehicles, curves were generated to project how much less deformation there would be if a baseline vehicle had a 2.5X roof strength (PRIA, Figure IV-D). This graph predicts that, compared to the baseline seven vehicles, the 2.5X standard would increase the roof crush energy by about 25%, so it would theoretically reduce the roof crush by about 25%. Using this 25% predicted reduction in roof crush, the 31 NASS fatalities were analyzed to see how much less roof crush (headroom) there would have been if the roof were a 2.5X roof. These predicted reductions in roof crush were then compared with the upright headroom in order to calculate the potential lives saved.

Unfortunately, there are a number of unsupported assumptions which are relied upon by the NHTSA to reach the ultimate benefits conclusions.

First, no attempt was made to determine the *actual* roof strengths of the vehicles in the 31 cases. It was assumed in this benefits model that all of the 31 NASS vehicles had the identical roof strength and that this was equal to the average of the seven vehicles that failed to pass the proposed 2.5X standard. It is likely, however, that many of the 31 NASS vehicles had roof strengths that already met the 2.5X standard. In fact, NHTSA's own analysis from the PRIA Section III-C projected that about 68% of the new passenger fleet already meets the 2.5X standard. If this number applies equally to the 31 NASS cases, then for 68% of those vehicles, the benefit calculations are meaningless.

Next, the 31 NASS case roof deformation analysis assumes there will be a reduction in roof deformation that is directly proportional to the increase in stiffness. The assumption is: If the roof is twice as stiff, the resulting roof damage will be half as much. Although this assumption seems logical, crash data and rollover and drop testing does not validate its accuracy. The 1995 Moffatt and Padmanaban (15) analysis of state-reported rollovers examined the relationship of FMVSS 216 roof strength with resulting roof damage. That study concluded: "There is no relationship between the likelihood of severe roof damage and roof strength in rollover accidents."

Although these results may seem counterintuitive, they were further articulated in 1996 from rollover testing conducted by Friedewald (16). He concluded that "the roof deformations are determined by the kinematics of the rollover. The associated contact forces are simply defined by roof strength. This connection shows a reinforcement of the roof only raises the value of the contact forces, but has no influence on body deformations."

Similar observations were made in 1998 by NHTSA's Rains and Van Voorhis (17) in their extensive set of FMVSS 216 roof crush tests and drop tests on a range of vehicles. They found that the amount of roof crush in a top drop was not necessarily proportional to the roof crush when tested by FMVSS 216 They observed that "This (reduction in roof crush) can be partially attributed to the rotation of the vehicle out of its set 216 angles after impact. The rotation changed the direction of the roof load and affected peak crush." Their observation is important because it identifies that, even in drop tests, the rotation of the vehicle leads to changing force directions on the roof, which leads to varying amounts of roof crush. When that understanding is applied to the roof-to-ground impacts in vehicles that are dynamically rolling, as seen in rollover crash testing, it is clear that there is even more variation in the duration and angle of force application than in a simple drop test.

NHTSA assumes that the amount of roof crush in a rollover is reduced proportionately to the increased crush energy of a stiffer roof. This assumption is fundamental to NHTSA's calculation of benefits, but it appears to be contrary to existing scientific literature, and no justification (such as a test program or scientific publication) is referenced in support of this critical assumption.

CORRELATION OR CAUSATION?

The preceding sections in this paper have addressed some of the technical difficulties with three of the factors in the fatality benefits model. There is an unexplained underlying assumption which the entire NHTSA benefit model is built upon; however, that potentially invalidates *all* of its conclusions. That assumption is that the increased roof crush found in the NASS cases was causally related to the increased injury in those cases.

The NHTSA finding that increased roof crush correlates with increased injury risk ("roof crush" is interpreted by NHTSA as "headroom reduction") is not a new finding. Numerous researchers have found similar results. Rains and Kanianthra (18) of NHTSA performed a similar headroom reduction analysis with a much smaller sample and reached the same conclusion: "The risk of head injury increases as the headroom is reduced." Henderson and Paine (19) noted: "Nearly all researchers … concede that severe deformation of the roof over an occupant's seating position *is associated with* severe injury to that occupant ….". Moffatt and Padmanaban (15) analyzed roof damage and injury outcome from state data including 90,000 occupants, and came to the same conclusion: "Rollovers with large roof damage have higher severe injury rates ….".

The question is not whether there is a relationship between roof crush and injury, but whether this is a *causal relationship* or whether the crush and injury are both independently associated with roof impact severity. This critical issue was specifically labeled for its importance in the NHTSA's Request for Comments in 2001: "It is important to determine if roof crush and injury are both associated with impact severity." As articulated by Partyka of NHTSA in 1992 (20): "It is not clear how to isolate the effect of roof intrusion on occupant injury severity because greater roof intrusion tends to occur with greater crash severity." Likewise, in the PRIA (3) NHTSA notes: "roof intrusion might be a surrogate for crash severity rather than a single cause of injury."

The PRIA quotes Partyka's specific concerns. It attempts to address rollover severity by controlling for the number of quarter turns. The NHTSA frankly states, however, that "the number of quarter turns provides a partial measure of rollover severity."

The reason quarter turns is only a "partial measure" is that the determining factor in the amount of roof impact damage is not necessarily quarter turns, but whether a vehicle lands on its roof or not. Numerous rollover crash tests demonstrate that when vehicles roll over, they do not roll like a ball with continuous contact with the ground. Instead, they typically impact the ground and bounce into the air, then impact again (8) (21). Sometimes the roof totally misses the ground, sometimes it grazes it, and sometimes it lands hard onto it. Segal and McGrath (22) in a 1980 report to NHTSA of 267 severe rollovers found that the determining factor associated with increased roof crush was not the number of rolls, but whether the vehicle came to rest on its roof.

NHTSA's "partial control" for rollover severity is just that. Those 31 vehicles with significant roof crush are likely those that happened to impact hard onto the roof. If there is any other explanation for the increased roof damage, such as those specific vehicles having unusually weak roofs, it is never offered by NHTSA.

Not once in the PRIA or the NPRM does NHTSA ever state that it concluded that there is a causal relationship. In fact, the existence of the "important" issue of whether roof crush is causally related to injuries is never addressed.

SUMMARY

1. NHTSA's fatality benefits model is based upon just 12 NASS cases, eight of which we suggest are unreliable (see Appendix). These are too few cases upon which to base a national estimate. NHTSA's attempt to expand the NASS data set by assuming a population of occupant statures, instead of the actual stature of the NASS occupant, does not reflect the over representation of young male drivers in rollovers.
2. If roof strength-to-weight ratio is included in the Austin study data analysis, the revised results show there is no statistically significant relationship between vehicle roof strength and likelihood of injury/fatality. The exact roof deformation shows up to be significant in predicting serious injury/fatality odds in rollovers. However, as discussed in detail in this paper, the relationship between roof deformation and crash severity is not addressed in NHTSA's statistical models.
3. The "effectiveness" factor (91.4%) is based upon maintaining positive "post-crash headroom". The underlying implication is that a belted occupant would not suffer head/face/neck injury from roof contact with positive post-crash headroom. This assumption ignores overwhelming scientific data that in current vehicles adults typically will have their head against the roof (zero headroom) during a rollover due to excursion within the seatbelt, even in the absence of any roof deformation. Additionally, the confidence level of the few cases making up the 91.4% estimate ranges from 70-100%. This means that, if the effectiveness rate was 70%, then the number of lives saved would be 10-34.
4. In the 12 fatal-case NASS analysis, NHTSA predicts how much reduced roof crush each of the 12 vehicles would have had if it incorporated the proposed 2.5X roof strength. Unfortunately, no attempt was made to determine the actual strength of each of those vehicles. NHTSA estimates that 68% of current vehicles already pass the proposed standard. If this estimate is correct, then 2/3 of the 12 cases are invalid, because those vehicles would have already passed the proposed standard.
5. The 20 vehicles tested to develop the 32.4% factor in the fatality model were highly significant. A change of one model could raise or lower the fatality prediction by 5%. For this factor to be reliable, those selected vehicles must be statistically representative of the current fleet. No evidence is presented to support the statistical validity of the selected 20 vehicles.
6. The entire premise of the NHTSA benefits model ignores the important issue of whether the correlation between roof crush and injury is a causal relationship. Despite NHTSA's specific recognition, in its 2001 Request for Comments, that this is "an important issue," it is never addressed in this NHTSA analysis presented four years later.

CONCLUSION

NHTSA's fatality benefits model incorporates numerous incorrect technical assumptions and is based upon far too little data. It is our conclusion that NHTSA's predicted annual fatality reduction of 13-44 lives from the new standard could statistically be equally as likely to be *zero* lives saved.

RECOMMENDATIONS

Although the outcome of our analysis for this paper has identified some weaknesses in NHTSA's statistical approach, we commend NHTSA for its comprehensive study to address this very complex issue in light of severe data limitations. NHTSA undertook a task with an immense volume of docket submissions, many with conflicting data and opinions and agendas, and was able to develop a proposed standard. The proposed standard has generated another round of comments, criticisms, and praise. Much of the analysis we find to be thorough and thought provoking. We hope that researchers will build upon the understanding which the proposed standard is generating.

We respectfully recommend some specific further undertakings by NHTSA which will better define this complex problem:

1. Address the issue of correlation versus causation. In our opinion, statistical data is properly used to identify correlations, but it cannot be used to determine causation. Understanding of causation comes only from understanding the physics of the relationship between two variables, and that comes

from physical testing. We suggest that NHTSA undertake a controlled rollover test or drop test program including dummies in order to explore:

- Headroom of belted occupants when inverted in current vehicles.
- The timing of roof crush and injury in current vehicles.
- The effects of stronger roofs in reducing dummy head/neck loads for vehicles with current headroom and seatbelt systems.
- The relationship between stronger roofs and the reduction in the amount of roof crush for typical roof-to-ground impacts.

2. Better define the range of upright and inverted headroom for drivers of current vehicles. Use the SAE H61 measurement (rather than Consumers Union's subjective estimate) and incorporate the change in seat positions made by vehicle occupants. Test how much additional headroom would be necessary for current restraints to keep a 50% occupant from contacting the roof when inverted.

3. Through testing, explore the potential reduction in vertical excursion that pretensioners, seat integrated restraints, and other advances safety devices might practically afford.

4. Acquire from manufacturers available roof strength data and head-to-roof rail measurements for all current vehicles, so that a more accurate estimate can be made regarding the percentage of the fleet that must be upgraded to meet the proposed 2.5X standard.

5. Include in their statistical model a roof strength-to-weight ratio variable to determine whether they find a relationship between likelihood of serious injury and vehicle roof strength. Also, explore the relationship between roof deformation and rollover crash severity factors.

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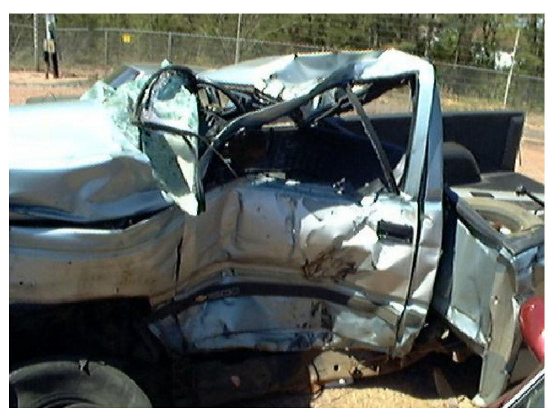
APPENDIX

As discussed in the text, NHTSA relied upon just 12 NASS rollover cases to justify over 99% of their projected fatality reduction. We believe that the following 8 of those 12 cases are not reliable indicators of the proposed benefits, typically because the rollovers were preceded by significant collisions which changed the roof structure and caused injuries that cannot be separated from the subsequent rollover injuries.

CASE 2001-81-131

This 1997 Saturn SL2 suffered a severe side impact during an intersection collision with a Kia Sephia. The delta velocity for the Sephia from the impact with the right door of the Saturn was estimated as 54 kph. The Saturn then rolled over and slid into a third vehicle. The right front occupant of the Saturn was a properly belted occupant 65-year-old male who died of an AIS 6 transected brainstem attributed to right roof rail contact. For this case to be relevant it must be assumed that (1) the right front occupant did not suffer the severe head injuries from the severe side impact into the door where he was seated, but later during the rollover, and (2) the side impact did not compromise the roof integrity, just as it would for the proposed new roof standard vehicle.

CASE 1997-48-006



This 1989 Chevrolet C/K pickup in an intersection collision was hit directly in its right door by a Navistar medium/heavy duty truck, and then rolled over one revolution. The 67-year-old driver of the pickup was restrained according to the NASS Occupant file, and unrestrained according to the NASS Case Summary. Pickup driver died within one hour. Cause of death listed as severe brain injuries and left sided “vault skull fracture massively depressed”. Driver also suffered multiple left rib fractures, left diaphragm laceration, and transected thoracic cord attributed to left side impact. For this case to be relevant, it must be assumed that (1) the severe left sided injuries to his head resulted from the single-revolution rollover and not from the high speed truck impact into his door, and (2) that the large truck impact into the pickup side/roof structure would not have compromised the roof structure of a vehicle with the proposed roof strength.

CASE 2002-09-182

This 1995 Dodge Caravan was in a very severe frontal collision with an International Harvester medium/heavy duty truck which had blown a tire and gone through the guardrail into oncoming traffic. The Caravan then rolled onto its roof. The frontal and left side damage to the caravan is massive, estimated as a “Delta V-barrier” of 83 kph. (No single photograph captures the damage fully). The seatbelted right front occupant was immediately fatal. He suffered massive injuries including AIS 5 brain injury, basilar skull fracture, AIS 5 bilateral rib fractures, and bilateral femur, tibia and fibula fractures. This extremely violent collision is only relevant to the proposed new standard if one assumes (1) the severe brain injury and skull fracture resulted from the rollover and not the frontal crash with the heavy truck, and (2) the massive destruction of the front and left side of the vehicle would not have compromised the roof of a new vehicle with the proposed roof standard.

CASE 2000-45-002

This 1992 Honda went off road and hit a low stone wall with a calculated delta-V of 64 kph, causing severe frontal and right side damage. The vehicle then pitched end-over-end and landed on its top. The belted driver was dead at the scene. His highest coded injury was an AIS 2 cervical spine fracture which was attributed to roof contact. For this case to be relevant it must be assumed that (1) the severe frontal and right A-pillar damage would not have compromised the roof of a vehicle with the new roof standard, and (2) that the cause of death was from the rollover and not the severe frontal/side impact with the wall.

CASE 2002-02-016

This 1997 Ford Probe left the road and impacted four large trees with its right side and roof. The properly belted driver was fatal at the scene. His most severe injury was an AIS 1 “minor scalp laceration” from roof contact. For this to be a relevant rollover case, it must be assumed that (1) the extremely severe right side and right roof damage from the tree did not compromise the roof strength, (2) the minor scalp laceration was not from the tree impacts, but was from the subsequent rollover, and (3) that the minor scalp laceration was either the cause of death or indicative of a more severe head impact which was the cause of death.

CASE 1999-43-169

This 1992 Toyota Paseo left the road and suffered a severe sideswipe with a tree, which caused significant left side roof and side damage, displacing the roof laterally beyond the seatback. It then rolled over. The properly belted driver was fatal at the scene. The injury coding found his most severe injury as an AIS 2 neck injury, which was attributed to left side roof rail contact where hair and blood was found. For this case to be relevant, it must be assumed that the significant side damage from the tree did not compromise the roof integrity, and it must be assumed that the neck injury came from the rollover and not from the more severe side impact.

CASE 2001-43-024

This 2001 Lincoln Town Car went over a guardrail and struck several trees and came to rest on its roof. The right front occupant was a properly belted 91-year-old female who was dead at the scene. Her most severe injuries were all coded as AIS 1 lacerations/ contusions/ abrasions, one of which was to her face. The occupants of this inverted vehicle waited 45 minutes for emergency personnel to arrive. For this case to be relevant it must be assumed that (1) the “minor facial laceration” was related to the cause of death, (2) that the 91-year-old occupant did not suffer more severe injuries which were unrecorded, and (3) that the inversion for 45 minutes was not a factor.

CASE 2001-41-016

This 1999 Geo Tracker swerved on road and rolled over 1-1/2 times. Belted driver was immediately fatal with cause of death described as “crushed head”. NASS investigation attributed the crushed head to contacting the interior of the roof. Accident investigators often see this massive trauma when a head is partially ejected and gets crushed between the roof and the ground, not from simply impacting the roof, because there is no “crushing” force under that circumstance. Relevance of this case to the proposed new roof standard is (1) the assumption that the immediately fatal “crushed head” resulted from contacting the interior of the roof, and (2) whether the new standard would prevent this injury.