DEPARTMENT OF TRANSPORTATION
National Highway Traffic Safety Administration
[Docket No. NHTSA-2015-0119]
New Car Assessment Program
AGENCY: National Highway Traffic Safety Administration (NHTSA), Department of Transportation (DOT).
ACTION: Request for comments.

SUMMARY: NHTSA's New Car Assessment Program (NCAP) provides comparative information on the safety of new vehicles to assist consumers with vehicle purchasing decisions and encourage motor vehicle manufacturers to make vehicle safety improvements. On December 16, 2015, NHTSA published in the Federal Register a "Request for comments" notice in which it described changes it plans to make to NCAP. The major planned changes discussed in the December 2015 notice still remain the same. Today's notice provides or references certain updates to information that notice contained. These updates include: (1) modifications to information or materials previously provided, (2) new information that completes the technical basis for the planned changes to NCAP, and (3) a discussion of the new 5-star safety rating system. Today's notice seeks comments on these modified and new materials as well as the new rating system.

DATES: Comments should be submitted no later than [60 days from publication date].

ADDRESSES: Comments should refer to the docket number above and be submitted by one of the following methods:

- *Federal Rulemaking Portal*: *http://www.regulations.gov*. Follow the online instructions for submitting comments.
- *Mail*: Docket Management Facility, U.S. Department of Transportation, 1200 New Jersey Avenue SE, West Building Ground Floor, Room W12-140, Washington, DC 20590-0001.

- *Hand Delivery*: 1200 New Jersey Avenue SE, West Building Ground Floor, Room W12-140, Washington, DC, between 9 a.m. and 5 p.m. ET, Monday through Friday, except Federal Holidays.
- *Instructions*: For detailed instructions on submitting comments see the Public Participation heading of the **SUPPLEMENTARY INFORMATION** section of this document. Note that all comments received will be posted without change to *http://www.regulations.gov*, including any personal information provided.
- *Privacy Act*: Anyone is able to search the electronic form of all comments received into any of our dockets by the name of the individual submitting the comment (or signing the comment, if submitted on behalf of an association, business, labor union, etc.). You may review DOT's complete Privacy Act Statement in the **Federal Register** published on April 11, 2000 (65 FR 19477). For access to the docket to read background documents or comments received, go to *http://www.regulations.gov* or the street address listed above. Follow the online instructions for accessing the dockets.

FOR FURTHER INFORMATION CONTACT: For crashworthiness issues, you may contact Ms. Jennifer N. Dang, Division Chief, New Car Assessment Program, Office of Crashworthiness Standards (Telephone: 202-366-1810). For crash avoidance and advanced technology issues, you may contact Mr. Clarke B. Harper, Crash Avoidance NCAP Manager, Office of Crash Avoidance Standards (Telephone: 202-366-1810). For legal issues, you may contact Mr. Stephen P. Wood, Office of Chief Counsel (Telephone: 202-366-2992). You may send mail to any of these officials at the National Highway Traffic Safety Administration, 1200 New Jersey Avenue SE, West Building, Washington, DC 20590-0001.

SUPPLEMENTARY INFORMATION:

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I. Executive Summary

In a December 16, 2015, “Request for comments” (RFC) notice (80 FR 78522), the National Highway Traffic Safety Administration (NHTSA) stated, “This notice announces the beginning of a process NHTSA believes will provide the agency with significantly enhanced tools and techniques for better evaluating the safety of vehicles, generating star ratings, and stimulating the development of even safer vehicles for American consumers, which the agency believes will result in even lower numbers of deaths and injuries resulting from motor vehicle crashes.” (80 FR 78522.) That notice described the agency’s plans for implementing the new tools and techniques and also noted, “As part of its efforts to support this NCAP upgrade, the agency will be completing additional technical work. The results of these efforts will be placed in the Docket as they are completed. Accordingly, we recommend that interested persons periodically check the Docket for new material.” (Id.)

Today's notice continues the process initiated on December 16, 2015, and provides notice to the public of: (1) certain updates to information and materials that were included in the December 16, 2015, notice, (2) the availability of new technical information and materials that have been completed since the earlier notice, and (3) a tentative description of the rating system for each of the three vehicle safety categories (crashworthiness, crash avoidance, and pedestrian protection) and the agency's current plan for the overall rating that would be derived from these ratings. Today's notice discusses this information under the appropriate subject matter headings that follow.

NHTSA is seeking comment on these modifications, the new technical information and materials, and the rating system described in today's notice. The agency is continuing its review of comments received in response to the December 16, 2015, notice. Those comments will not be fully discussed in this notice, as the agency plans to consider them in the final decision notice. However, the new rating system is discussed in detail in this notice because numerous commenters requested that NHTSA provide additional information on the new rating system for the planned program upgrades. Since the agency completed its validation testing and the development of the new rating system, the agency is seeking comments on its entirety. The agency intends to implement enhancements to NCAP in 2019 beginning with the 2020 model year (MY) instead of 2018 (as stated in the December 2015 RFC notice) to allow sufficient time for addressing public comments received from both the December 2015 RFC notice and this supplemental notice. Lastly, as discussed in subsequent sections, the agency may consider rulemaking action in certain program areas where appropriate.

II. Background

NCAP provides comparative information on the safety performance and features of new vehicles to: (1) assist consumers with their vehicle purchasing decisions, (2) encourage manufacturers to improve the current safety performance and features of new vehicles, and (3) stimulate the addition of new vehicle safety features. NCAP is one of many tools NHTSA uses to fulfill its mission, which is to reduce the more than 30,000 deaths and 2 million injuries on U.S. roadways that result from vehicle crashes each year.[1] NCAP has a proven legacy of driving effective vehicle safety improvements. Advancements to NCAP represent an opportunity to save more lives and prevent more injuries.

Thus, on December 16, 2015, NHTSA announced in a *Federal Register* notice its plan to use enhanced tools and techniques for evaluating the safety of vehicles, generating star ratings, and stimulating the development of even safer vehicles for American consumers. These include:

- A new frontal oblique test to address a crash type that continues to result in deaths and serious injuries despite the use of seat belts, air bags, and the crashworthy structures of late-model vehicles;
- Use of the THOR 50th percentile male Metric (THOR-50M) anthropomorphic test device (ATD – i.e. crash test dummy) in the frontal oblique and full frontal tests because of its advanced instrumentation and more human-like (biofidelic) response to the forces experienced in these crashes;

[1] In 2015, the latest year for which complete annual statistics are available, 35,092 people were killed and 2.4 million people were injured in motor vehicle crashes on U.S. roadways. While showing slight fluctuation in recent years, traffic crash fatalities and injuries have been in a general decline with fatalities decreasing 25 percent and the number of people injured decreasing 13 percent from 2005 to 2014. However, figures for the first six months of 2016 showed a 10.4 percent increase in traffic crash fatalities as compared to the first six months of 2015.

- Use of the WorldSID 50^{th} percentile male ATD (WorldSID-50M) in both side pole and side moving deformable barrier (MDB) tests because of its advanced instrumentation and enhanced human-like (biofidelic) properties;
- Pedestrian crashworthiness testing to measure the extent to which vehicles are designed to minimize injuries and fatalities to pedestrians struck by vehicles;
- An update of the rollover static stability factor (SSF) risk curve using only crash data from newer electronic stability control (ESC)-equipped vehicles;
- The addition of rating multiple new advanced technologies to a group of technologies (forward collision warning, lane departure warning, and rearview video systems) already recommended by NCAP;
    - These new technologies will include blind spot detection, lower beam headlighting technologies, semi-automatic headlamp beam switching, and amber rear turn signal lamps. The agency added crash imminent braking and dynamic brake support technology recommendations to NCAP via a separate proceeding.[2]
- A new rating system that would incorporate significantly more vehicle safety information derived from the various additions to NCAP described immediately above and in more detail throughout this notice. In other words, the new rating system would include ratings from the crashworthiness, crash avoidance, and pedestrian protection areas.

The planned changes to NCAP – those unveiled in the December 2015 RFC notice, those in today's notice, and those further supported by additional and updated technical information

[2] 80 FR 68604.

and additional discussion of the new NCAP rating system – demonstrate the agency's intent to improve vehicle safety.

III. Purpose and Rationale

In its December 16, 2015, RFC notice, NHTSA stated that additional materials relating to the planned changes to NCAP described in the notice were still in progress and would be made available to the public upon their completion. The purpose of this notice is to formally provide notification of their availability. Specifically, this notice discusses the availability of additional information pertaining to the frontal and side crashworthiness tests and test devices. Likewise, it discusses additional information pertaining to crashworthiness and crash avoidance pedestrian protection. Finally, this notice details the agency's current plan and thinking for rating vehicles under the next program upgrade and outlines a potential points-based rating system with upper and lower bounds for crashworthiness assessment. This is a paradigm shift from the approach used in the current rating system because it allows more flexibility in the way NCAP assesses injuries from various body regions, which allows the program to rate vehicles in a way that provides better differentiation of safety among vehicles.

The agency is publishing this supplement to the December 2015 RFC notice to provide the public sufficient notice of additional and modified materials as well as a more fully described rating system and now believes that it has provided sufficient information to the public to support all changes that were initially proposed in the December 2015 RFC notice. The agency notes that it may conduct additional research between the publication of this notice and any final decision. However, the agency believes that additional research will solely be to validate the testing and research already completed and will not result in substantive changes to the planned program changes. The agency expects comments on these materials to be received within the time period indicated in this notice.

IV. Areas Under Consideration for Inclusion in Advancement of NCAP

A. Frontal Crashworthiness

1. Full Frontal Rigid Barrier Test

As stated in the December 2015 RFC notice, NCAP intends to continue conducting its current full width frontal rigid barrier test at 56 km/h (35 mph). As shown by the Fatality Analysis Reporting System (FARS) data described and discussed in appendix I, frontal crashes continue to be a significant source of fatalities in the field. NHTSA tentatively intends to update the ATDs to evaluate occupant protection in NCAP's full frontal crash, and is considering use of the THOR-50M dummy in the driver's seat as well as the HIII-5F dummy in the right front passenger's and right rear passenger's seats. For the reasons discussed in the December 2015 RFC notice, the agency currently plans to place the right front seat HIII-5F passenger at the mid-track position rather than the full-forward position that it is currently tested for compliance and NCAP purposes. NHTSA seeks comments on these plans.

Since the December 2015 RFC notice, the agency has conducted full frontal rigid barrier research tests with the HIII-5F dummy seated in the right front passenger seat's mid-track position (instead of the forward-most position) and a HIII-5F dummy seated in the right rear seat. A summary of this testing is included as a report in the docket containing this notice.[3] The agency is seeking public comment on the results of this testing.

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[3] "Occupant Response Evaluation in NCAP Pilot Full Frontal Rigid Barrier Impact Crash Testing" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

2. Frontal Oblique Test

As stated in the December 2015 RFC notice, NCAP also plans to test and rate new vehicles under the frontal oblique testing protocol referenced in that document.[4] The agency is providing additional support for its intention to use the frontal oblique test in NCAP via a report titled "Repeatability and Reproducibility of Oblique Moving Deformable Barrier Test Procedure."[5] This document details results from oblique tests conducted on one vehicle make and model at the same testing laboratory, and across several different laboratories. It also concluded that the performance of the Oblique Moving Deformable Barrier (OMDB), target vehicle, and driver ATD responses exhibited overall good repeatability and reproducibility (R&R) as defined in that document.[6] Results from twelve agency oblique tests are also included as appendix VIII of this document.

3. Frontal Test Dummies

a. THOR 50th Percentile Male (THOR-50M) ATD

The December 2015 RFC notice presented NHTSA's plan to include the THOR-50M ATD in both frontal NCAP crash test modes. NHTSA believes that the THOR-50M, which is a more sensitive evaluation tool, could be used in NCAP to better differentiate vehicle safety performance. The THOR-50M has enhanced biofidelity and advanced instrumentation in the thorax, abdomen, and lower extremities that is not available with the HIII-50M ATD. The agency continues to believe that the HIII-50M ATD is sufficient for regulatory use because it provides the injury measures that are assessed in current regulations. In the future, the agency

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[4] Available at http://www.regulations.gov/document?D=NHTSA-2015-0119-0017.
[5] Located in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[6] Repeatability is defined as the similarity of responses from a single dummy when subjected to multiple repeats of a given test condition, whereas reproducibility is defined as the similarity of test responses from multiple dummies when subjected to multiple repeats of a given test condition.

may consider amending Part 572 to include the THOR-50M. The agency plans to use this test device in both the driver and front passenger seating positions in the frontal oblique test as well as in the driver seating position in the full frontal rigid barrier test.

Since the December 2015 RFC notice, the agency has updated the qualification procedures, the THOR-50M ATD drawing package, a list of revisions made to the drawings, and its parts list.[7] NHTSA is aware of several differences between the updated THOR-50M ATD drawing package and that for the commercially-available versions of the THOR-50M ATD. These differences came about because NHTSA and an ATD manufacturer, working independently, each developed their own set of fixes to resolve several usability and durability issues. The two sets of fixes differ slightly, resulting in some distinct, but functionally equivalent, parts. NHTSA is reviewing the alternative designs for these items. NHTSA is also aware of differences in qualification response between its THOR-50M ATDs and the commercially-available versions. NHTSA has identified several items in the "THOR 50th Percentile Male (THOR-50M) Qualification Procedures Manual, August 2016" which may require modifications to the procedures and/or specifications to reconcile these differences.[8] Documents detailing any resulting changes to the THOR-50M ATD drawing package and qualification procedures will be submitted to the docket prior to the final decision notice.

The document that describes the procedures for assembly, disassembly, and inspection (PADI) of the THOR-50M ATD is also being included in the docket for this notice.[9] Additional

[7] Updated documents in NHTSA-2015-0119 at https://www.regulations.gov/docket?D=NHTSA-2015-0119: "THOR 50th Percentile Male (THOR-50M) Qualification Procedures Manual, August 2016" (NHTSA-2015-0119-0361), "Parts List and Drawings, THOR-50M Advanced Frontal Crash Test Dummy, August 2016," "THOR-50M Drawing Revisions, August 2016," and "Drawing/Parts List THOR-50M Advanced Frontal Crash Test Dummy, August 2016."

[8] Located in NHTSA-2015-0119, available at https://www.regulations.gov/document?D=NHTSA-2015-0119-0361.

[9] "THOR 50th Percentile Male (THOR-50M) Procedures for Assembly, Disassembly, and Inspection (PADI) September 2016" available in NHTSA-2015-0119 at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

supporting documents for this test device are provided in the docket containing this notice as well as summarized in the sections below.

i. Biofidelity

A separate report, titled "THOR-50M Biofidelity Report," pertains to the biofidelity of the THOR-50M ATD and is included in the docket for this notice.[10] This report concludes that most of the internal and external BioRank scores for the THOR-50M ATD were below 2.0, which was defined as "good" biofidelity. When looking at those results by body region, the internal and external BioRank scores for THOR-50M ATD are all below 2.0 except for neck internal and external biofidelity, and abdomen external biofidelity, which are marginal. The agency believes the THOR-50M is especially more suitable for inclusion in the frontal oblique test than the HIII-50M because of its more human-like response in that loading condition. The agency is seeking comment on this biofidelity report.

ii. Repeatability and Reproducibility (R&R)

A standalone document detailing the R&R work conducted in support of the THOR-50M is also being included in the docket containing this notice.[11] This report found that the THOR-50M typically rates "good" or "excellent" for most body regions when considering the coefficient of variation (CV) from repeated qualification tests.[12] Since both the THOR-50M and HIII-50M have been shown to be repeatable and reproducible test devices, comparing them in terms of R&R is not necessary. The agency is seeking comment on the THOR R&R report and the findings included therein.

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[10] Located in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[11] "THOR-50M Repeatability and Reproducibility of Qualification Tests" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[12] Ibid.

iii. Validation Tests

The agency conducted a series of tests using the THOR-50M ATD in the seating positions referenced in the December 2015 RFC notice for the planned upgrade. These included oblique tests with the THOR-50M ATD as the driver and right front passenger as well as full frontal rigid barrier tests with the THOR-50M ATD as the driver. The results of some agency oblique tests are contained in appendix XV and discussed in the ratings system section of this document. Others are discussed in a report being included in this docket.[13] Results from the agency's analysis of full frontal testing with the THOR-50M are contained in appendix VII as well as a report included in the docket containing this notice.[14]

iv. Durability

A separate report included in the docket for this notice, "THOR-50M Durability Report," details the agency's work to determine whether the durability of the THOR-50M ATD is acceptable.[15] Elevated energy qualification tests on the head, face, neck, thorax, abdomen, knee, and upper and lower leg were conducted on several THOR dummies. The majority of the results initially demonstrate that the ATD exhibits good durability. Design and drawing changes implemented for the iliac and front neck cable are included in the updated August 2016 drawing package, which is in the docket for this notice.[16] As previously noted, other changes may be forthcoming. The agency is seeking comment on the THOR-50M durability report.

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[13] "Repeatability and Reproducibility of Oblique Moving Deformable Barrier Test Procedure" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[14] "Occupant Response Evaluation in NCAP Pilot Full Frontal Rigid Barrier Impact Crash Testing" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[15] Located in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[16] "Drawing/Parts List THOR-50M Advanced Frontal Crash Test Dummy, August 2016" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

v. Injury Criteria and Risk Curves

The agency discussed its preliminary injury criteria for the THOR-50M ATD in the December 2015 RFC notice. A detailed injury criteria report for the THOR-50M ATD is included in the docket for this notice.[17] Modifications to certain criteria and risk curves are described below and summarized in that document as well as in appendix II of this notice. The agency has also included in the docket for this notice a step-by-step post-processing procedure for calculation of the injury assessment values and associated injury risk for the injury criteria for use with the THOR-50M.[18]

The agency is planning to use the risk curves in this document differently than it uses the existing risk curves in the current NCAP. Rather than using the formulae (risk functions) to calculate injury probabilities for each body region measured during testing, NHTSA is considering them as a tool to set lower and upper performance limits for assessing the data instead. Details on the selection and application of these lower and upper limits that are used to set the boundaries for the linear scale, points-based crashworthiness rating calculations are presented later in the "Crashworthiness Rating" section of this document. The agency is seeking comment on the following:

HEAD – NHTSA intends to use the head injury criterion (HIC_{15}) shown in appendix II as one metric for assessing head injury risk using the THOR-50M ATD in frontal crashes. This criterion is currently in use in FMVSS No. 208 and frontal NCAP tests. As described in the 2008

[17] "Injury Criteria for the THOR 50th Male ATD," in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[18] "THOR-50M Post-processing for Injury Criteria Calculation," in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

NCAP Final Decision Notice[19], the risk curve associated with HIC_{15} in frontal NCAP testing represents a risk of an AIS 3+ injury.

HIC_{15} was developed based on skull fracture data.[20] In frontal NCAP tests, measured HIC_{15} values have decreased significantly since 1993. Despite this decrease, brain injuries continue to occur. For belted occupants, brain injuries are approximately eight times more common than skull or facial fractures, and the cumulative societal cost of brain injuries is roughly ten times the cost of skull and facial fractures.[21] To address brain injuries, the agency currently plans to use the Brain Injury Criterion (BrIC).[22] BrIC was established after considering many different formulations, including those considering angular acceleration components. The final BrIC formulation was found to have the highest correlation to two strain metrics measured in the brain. These strain metrics, cumulative strain damage measure (CSDM) and maximum principal strain, are the mechanical measures that have been shown to be directly associated with brain injury potential.[23] BrIC is calculated by combining the angular velocities of the head about its three local axes compared to directionally dependent critical values. The agency tentatively

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[19] 73 FR 40016, Docket No. NHTSA–2006–26555–0114, available at https://www.regulations.gov/document?D=NHTSA-2006-26555-0114.

[20] Eppinger, R., Sun, E., Bandak, F., Haffner, M., Khaewpong, N., Maltese, M., & Saul, R., "Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems II," NHTSA Docket No. NHTSA–1999–6407–5, 1999; 72 FR 3473. Docket No. NHTSA–2006–26555–0006. available at https://federalregister.gov/a/E7-1130.

[21] "Injury Criteria for the THOR 50th Male ATD," in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

[22] Takhounts, E., Eppinger, R., Campbell, J., Tannous, R., Power, E., Shook, L., "On the Development of the SIMon Finite Element Head Model." Stapp Car Crash Journal, Vol. 47 (October 2003), pp. 107-133, available at http://www.nhtsa.gov/DOT/NHTSA/NVS/Biomechanics%20&%20Trauma/SIMon/Stapp2003%20Takhounts.pdf; Takhounts, E., Ridella, R., Hasija, V., Tannous, R., Campbell, J., Malone, D., Danelson, K., Stitzel, J., Rowson, S., Duma, S., "Investigation of Traumatic Brain Injuries Using the Next Generation of Simulated Injury Monitor (SIMon) Finite Element Head Model," Stapp Car Crash Journal, Vol. 52 (November 2008), pp. 1-31, available at http://www.nhtsa.gov/DOT/NHTSA/NVS/Biomechanics%20&%20Trauma/SIMon/Stapp2008%20Takhounts.pdf.

[23] Takhounts, E., Eppinger, R., Campbell, J., Tannous, R., Power, E., Shook, L., "On the Development of the SIMon Finite Element Head Model." Stapp Car Crash Journal, Vol. 47 (October 2003), pp. 107-133, available at http://www.nhtsa.gov/DOT/NHTSA/NVS/Biomechanics%20&%20Trauma/SIMon/Stapp2003%20Takhounts.pdf; Takhounts, E., 2015. "Computational Modeling and Injury Criteria for Motor-Vehicle Crashes," 59th Stapp Car Crash Conference, Invited Lecture, New Orleans, LA. available at http://www.nhtsa.gov/DOT/NHTSA/NVS/Biomechanics%20&%20Trauma/Stapp_2015.pdf.

plans to use the same formulation of BrIC that was provided in the December 2015 RFC notice, which is also listed in appendix II of this document. The document titled, "Injury Criteria for the THOR 50th Male ATD" discusses the additional data the agency examined to consider a different BrIC risk curve than that presented in the December 2015 RFC. Extensive details on the selection of the BrIC AIS 4+ CSDM risk curve the agency is now considering are described in that document.[24]

NECK – In the December 2015 RFC notice, the agency provided the public with two potential methods for assessing neck injury for the THOR-50M in frontal crashes. Further analysis of existing data, as discussed in "Injury Criteria for the THOR 50th Male ATD," allowed NHTSA to develop the Nij risk curves presented there and in appendix II of this document.[25]

At this time, NHTSA intends to use modified, THOR-50M-specific versions of the neck injury criterion (Nij) as metrics for assessing neck injury in frontal crashes, and is no longer considering adopting CNij. These functions were not presented in the December 2015 RFC notice, but are detailed in "Injury Criteria for the THOR 50th Male ATD," included in this docket and summarized in appendix II of this document.[26] The agency intends to use both AIS 2+ and AIS 3+ risk functions to set upper and lower performance limits to assess THOR-50M Nij readings. Further details are presented in the ratings system section later in this document. The current formulation of Nij is still retained for both formulae, but a human cadaver-based set of critical intercepts are planned for use to specifically represent the THOR-50M. These values, which are based on a comprehensive review of available experimental data, are detailed in

[24] Located in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[25] Ibid.
[26] Ibid.

"Injury Criteria for the THOR 50th Male ATD."[27] These critical values are based on measurements from the upper neck load cell alone: 4,200 newtons (N) in tension, 6,400 N in compression, 88.1 newton meters (Nm) in flexion, and 117 Nm in extension. As the cadaver-based values represent a "relaxed" human, this is a conservative estimate of injury risk because it does not account for additional resistance to tension provided by neck musculature.[28]

CHEST – In the December 2015 RFC notice, NHTSA previously outlined its intention to use one or more multi-point thoracic injury criteria to predict chest injury. At this time, the agency is presenting new multi-point risk curves to evaluate the risk of chest injury in the THOR-50M. Of the available thoracic measurements, the peak resultant deflection, calculated using the maximum of the peak resultant chest deflections from the four 3D InfraRed-Telescoping Rod for Assessment of Chest Compression (IR-TRACC) assemblies in the THOR rib cage, was selected as the most reasonable predictor. Age was determined to be a significant covariate in the prediction of injury, but not mass, stature, or sex. The development of these formulae is described in a report in this docket.[29] The AIS 3+ risk curve that the agency is considering to set limits for assessing chest injury with the THOR-50M is available in appendix II of this notice.

ABDOMEN – In the December 2015 RFC notice, NHTSA acknowledged that assessing a peak abdominal deflection injury measurement for the THOR-50M using IR-TRACCs was a new area of exploration for the agency. Although the risk curve presented in appendix II of this document and in "Injury Criteria for the THOR 50th Male ATD" is different from that included

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[27] Ibid.
[28] Dibb, A., Nightingale, R., Chauncey, V., Fronheiser, L., Tran, L., Ottaviano, D., & Myers B., "Comparative Structural Neck Responses of the THOR–NT, Hybrid III, and Human in Combined Tension-Bending and Pure Bending," Stapp Car Crash Journal, 50: 567–581, 2006.
[29] "Injury Criteria for the THOR 50th Male ATD," in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

in the December 2015 RFC notice, NHTSA still intends to use a measurement of peak abdominal deflection to assess abdominal injury for the THOR-50M.[30] The injury criterion presented is based on testing of porcine surrogates, and the study indicated that percent compression was the best injury discriminator compared to other metrics that were considered.[31] Accordingly, the risk function was developed to relate the peak compression of the THOR-50M abdomen, which was measured using bi-lateral 3D IR-TRACC assemblies in the lower abdomen, to the risk of AIS 3+ abdomen injury. The limit the agency is considering for assessing abdomen injury with the THOR-50M and this risk function are presented later in this document.

PELVIS – NHTSA announced in the December 2015 RFC notice its plan to use acetabulum load criteria to assess potential pelvis injuries with the THOR-50M. Since the publication of the December 2015 RFC notice, NHTSA plans to use different acetabulum load criteria, explained below, to assess potential pelvis injuries with the THOR ATD. In that notice, the agency explained that the scaling ratio used for the acetabulum risk curve presented there "may not be appropriate for the THOR–50M ATD because the biofidelity of the femur was updated in the Modification Kit." As such, the agency revisited the formulation and updated the criteria to represent the biofidelity of the THOR-50M. The development of this new risk function is detailed in "Injury Criteria for the THOR 50th Male ATD" and the risk function itself is listed in appendix II.[32] The agency is considering this risk function to set limits for assessing injury to the THOR-50M, a process described later in this document.

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[30] Ibid.

[31] Kent, R., Stacey, S., Kindig, M., Woods, W., Evans, J., Rouhana, S., Higuchi, K., Tanji, H., St. Lawrence, S., Arbogast, K., "Biomechanical Response of the Pediatric Abdomen, Part 2: Injuries and Their Correlation with Engineering Parameters," Stapp Car Crash Journal, Vol. 52, November 2008.

[32] "Injury Criteria for the THOR 50th Male ATD," in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

FEMUR/KNEE – NHTSA announced its intention to use peak femur axial force as a metric for assessing femur injury risk in frontal crashes in the December 2015 RFC notice. As currently used in FMVSS No. 208 and frontal NCAP tests, the injury risk function does not account for the difference between the applied force at the knee of the post-mortem human surrogate (PMHS) used to develop the risk function and the peak axial compression force measured at the femur load cell of the ATD. A correction factor is applied to the peak axial compression force measured at the femur load cell of the THOR-50M to account for this difference, resulting in the risk function for AIS 2+ knee and distal femur injury shown in "Injury Criteria for the THOR 50th Male ATD" and in appendix II of this document.[33] The agency is considering the risk function to set limits for assessing femur injury risk with the THOR-50M.

LOWER LEG – NHTSA presented several lower leg injury criteria for consideration in the December 2015 RFC notice. Although the agency still intends to assess upper tibia force, lower tibia force, and tibia bending moment for the THOR-50M, it no longer plans to assess ankle injuries for this ATD. The agency evaluated new data and is considering the three new risk curves presented in appendix II to set limits for assessing lower leg injuries.[34] NHTSA developed these risk curves for the prediction of: (1) tibia plateau fractures using the axial force measured by the upper tibia load cell; (2) tibia/fibula shaft fractures using the resultant moment calculated using measurements from the upper and lower tibia load cells; and (3) distal tibia, calcaneus, talus, ankle, and midfoot fractures using the axial force measured by the lower tibia load cell. The axial load criteria address the most common injury mechanism for many of the leg structures. The combined stress approach represented by the Tibia Index and Revised Tibia

[33] Ibid.
[34] Ibid.

Index is no longer being examined for the THOR-50M because the simplified approach of using only the resultant moment was deemed more sufficient.[35] Assessing fracture risk based on the resultant moment will address bending occurring in the leg from external loading sources and ankle rotation.

b. Hybrid III 5th Percentile Female (HIII-5F) ATD with RibEye™

In the December 2015 RFC notice, NHTSA stated its plan to use the HIII-5F ATD currently used in the full frontal rigid barrier test with new RibEye™ instrumentation for measuring chest deflection. In that notice, the agency considered using the HIII-5F with RibEye™ in the right front passenger's seat and the second row right passenger's seat. Seating procedures for positioning the two HIII-5F dummies in that test were also docketed with the December 2015 RFC.[36]

NHTSA conducted research with the HIII-5F that it is planning for use in NCAP. The agency collected data on the functionality of the RibEye™ system[37] as well as the suitability of using head angular rate sensors (ARS) with this ATD.[38] As a result of this research, the agency is not planning to use the RibEye™ system with the HIII-5F ATD and will continue to use the chest potentiometer in this NCAP upgrade. In addition, the agency assessed the usability of a HIII-5F ATD with a new harmonized chest jacket and spine box.[39]

[35] Ibid.
[36] The draft HIII-5F right front passenger seating procedure is located at NHTSA-2015-0119-0007 and the draft HII-5F right rear passenger seating procedure is located at NHTSA-2015-0119-0008.
[37] "Occupant Response Evaluation in NCAP Pilot Full Frontal Rigid Barrier Impact Crash Testing," in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[38] "R&R Report for the Neck of the Hybrid III 5th Percentile Female Dummy with 3aω Redundant Accelerometer Head, August 2016" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[39] "Evaluation of the Hybrid III 5th Percentile Female (HIII-5F) Dummy Used in the New Car Assessment Program – Inspection & Qualification and Sled Test Repeatability and Reproducibility & Performance in Low Risk Deployment Out-of-Position (OOP) Tests" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

In the docket containing this notice, the agency is providing technical specifications to describe the version of the HIII-5F ATD it is planning to use in NCAP, which differs in various ways from the current version used by NCAP, as discussed below.[40] An updated parts list, updated drawings, and documents detailing the modifications being considered for use with this ATD in NCAP are also being included in this docket.[41] A PADI document detailing how to install angular rate sensors and replace the spine box and chest jacket is also being included.[42]

i. Addition of Head Angular Rate Sensors (ARS)

The agency conducted repeatability testing with the HIII-5F head and neck assembly with angular rate sensors (ARS) sensors installed.[43] Angular rate sensors are used to measure the angular velocity of the head about its three local axes. This data is used in the calculation of BrIC. HIII-5F heads were reconfigured from the six accelerometer setup (three primary channels and three redundant channels), normally used in NCAP, to include the ARS. Each head contained three primary accelerometers, three redundant accelerometers, and three angular rate sensors. This is referred to as the 3aω redundant accelerometer head. The ARS were installed in a way that kept the location of the center of gravity (CG) of the head nearly the same while maintaining the specification of the mass moment of inertia.

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[40] "Technical Specifications for the Hybrid III 5th Percentile Female Test Dummy – New Car Assessment Program, August 2016" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

[41] "Parts List and Drawings – NCAP Hybrid III 5th Percentile Small Adult Female Crash Test Dummy, August 2016," "Parts List and Drawings - NCAP - Hybrid III 5th Percentile Small Adult Female Crash Test Dummy, August 2016, "Modifications to: Drawing Package, Hybrid III 5th Percentile Female Test Dummy, Part 572 Subpart O For use in the New Car Assessment Program, August 2016" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

[42] "Procedures for Assembly, Disassembly, and Inspection (PADI) of the Hybrid III 5th Percentile Female Test Dummy – New Car Assessment Program, August 2016" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

[43] "R&R Report for the Neck of the Hybrid III 5th Percentile Female Dummy with 3aω Redundant Accelerometer Head, August 2016" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

This configuration was chosen so as not to affect the biofidelity of the neck, and was followed by a series of neck qualification tests.[44] Five repeat tests were performed for each dummy neck in each qualification test mode. Data was compiled for each dummy in order to evaluate repeatability, and then also for all three dummies combined in order to evaluate reproducibility. The CV percent values for the neck in extension and flexion showed excellent repeatability and reproducibility and the neck responses were within the existing Code of Federal Regulations (CFR) specifications.[45] When head drop tests were conducted, the three angular rate sensors (when tested along with the 3aω redundant accelerometer head) showed excellent repeatability when compared to the performance of the HIII-5F baseline head.[46] The maximum resultant and lateral head acceleration responses were all within the qualification specifications.

ii. Harmonized Chest Jacket and Spine Box Upgrade

Since 2011, NCAP has been using two brands of HIII-5F dummies (manufactured by companies then-named FTSS and Denton) to evaluate right front passenger occupant safety in frontal crashes. Per the current NCAP procedure, OEMs may select the dummy brand NCAP uses when testing their products.[47] In order to assess occupant protection in the right front passenger and rear seat of future full frontal rigid barrier NCAP tests, the agency is planning to use a version of the HIII-5F with a harmonized chest jacket and spine box. SAE coordinated the

[44] Tests were conducted according to 49 CFR 572.133 - Neck assembly and test procedure.
[45] "R&R Report for the Neck of the Hybrid III 5th Percentile Female Dummy with 3aω Redundant Accelerometer Head, August 2016" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[46] The baseline HIII-5F head was configured according to 49 CFR 572.132 – Head assembly and test procedure. Only CG accelerometers were installed.
[47] "Laboratory Test Procedure for New Car Assessment Program Frontal Impact Testing, October 2015," NHTSA-2015-0046-0010, available at https://www.regulations.gov/document?D=NHTSA-2015-0046-0010.

development of this harmonized chest jacket and spine box in order to correct dimensional inconsistencies in the chest jacket drawings and eliminate mechanical issues in the spine box.[48]

The agency evaluated two dummies with the harmonized chest jackets and the spine boxes in 2011.[49] The new chest jacket is designed in such a way that it can be fitted over the two dummy brands. The dummies in that study passed the thoracic qualification test with excellent R&R based on peak CV and good reproducibility based on the average CV.[50] The harmonized chest jacket and upgraded spine box dummy R&R was also assessed using sled tests. Based on peak CV values, the resultant chest acceleration responses had good to excellent repeatability and excellent reproducibility. The values of chest deflection also exhibited good to excellent repeatability, and acceptable reproducibility.

iii. Validation Testing

A report analyzing the results from recent agency fleet testing containing the HIII-5F is included in the docket containing this notice.[51] In this research series, the agency conducted 12 full frontal rigid barrier tests with an HIII-5F ATD seated in the front and rear seat of each vehicle. RibEye™ systems were installed in both HIII-5F ATDs to collect chest deflection data in addition to that from the single point chest potentiometer.[52] The head of the front seat HIII-5F dummy was also equipped with ARS sensors. NHTSA is seeking public comment on this

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[48] SAE International Surface Vehicle Information Report, "H-III 5F Chest Jacket Harmonization," SAE Standard J2921 Jan 2013, available at http://standards.sae.org/j2921_201301/; SAE International Surface Vehicle Information Report, "H-III 5F Spine Box Update to Eliminate Noise," SAE Standard J2915 May 2011, available at http://standards.sae.org/wip/j2915_201108/.
[49] McFadden, J., Stricklin, J., "Evaluation of the Hybrid III 5th Female Modified Chest Jacket & Spine Box." 22nd International Technical Conference on the Enhanced Safety of Vehicles, Paper Number 11-0334, 2011, available at http://www-nrd.nhtsa.dot.gov/pdf/esv/esv22/22ESV-000334.pdf.
[50] Ibid. Note that as defined in that study, a peak or average CV <5 was considered "excellent" while 5<CV<8 was considered "good."
[51] "Occupant Response Evaluation in NCAP Pilot Full Frontal Rigid Barrier Impact Crash Testing" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[52] Chest deflection transducer as referenced in 49 CFR 572.134 – Thorax assembly and test procedure.

report.[53] As a result of the research presented there, the agency is not planning to use the RibEye™ system with the HIII-5F ATD in this NCAP upgrade. The agency will make a final assessment on all planned HIII-5F seating procedures and remaining instrumentation in the final decision notice.

iv. Injury Criteria and Risk Curves

The agency is considering the use of the risk curves in appendix III of this document to inform the lower and upper performance limits for assessing the occupant injury risk predicted by the HIII-5F ATD. As with the THOR-50M, these lower and upper limits would be used to set the boundaries for the linear scale, points-based crashworthiness rating calculations presented later in the document. The following sections detail modifications to certain injury criteria that were planned for this NCAP upgrade and discussed in the December 2015 RFC notice.

HEAD – The agency still plans to assess the risk of head injury to the front seat HIII-5F ATD in the full width rigid barrier test by calculating both HIC_{15} and BrIC as listed in appendix III. As the document titled, "Injury Criteria for the THOR 50th Male ATD" demonstrates, the single formulation of BrIC being considered is sufficient for the HIII-5F as well as all other ATDs examined.[54] Further examination of the BrIC AIS 4+ CSDM risk curve the agency is considering is described in that same report. The ways in which these risk curves are being considered to set performance limits for assessing injury with this occupant are discussed later in this document.

The agency only plans to assess the risk of head injury to the rear seat HIII-5F ATD in the full width rigid barrier test if head contact with forward vehicle interior objects (e.g. the front

53 "Occupant Response Evaluation in NCAP Pilot Full Frontal Rigid Barrier Impact Crash Testing" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
54 Located in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

row seat back) occurs during the event. Though no instances of this head contact were observed for the rear seat HIII-5F ATD in any of the agency's recent full frontal rigid barrier tests, NHTSA is seeking comment on the appropriateness of including a head contact assessment for this ATD in NCAP.[55] The agency is considering a procedure similar to Japan NCAP.[56] However, rather than using the SAE International Standard J2052 procedure like that program does, NHTSA would use the HIII-5F HIC_{15} calculation from appendix III to assess the head injury risk to this occupant.[57] If it is determined, through chalk, video, or other data analysis, that head contact with the front seat occurs, NHTSA would calculate head injury risk for that occupant according to the HIC_{15} formula listed in appendix III.

NECK – NHTSA is planning to evaluate neck injury for the HIII-5F ATD in the front seat using the Nij formula listed in appendix III, which is identical to the formula listed in the December 2015 notice and fitted to a risk of 0 percent injury when Nij is 0. The agency does not plan to assess the risk of neck injury for the HIII-5F seated in the rear seat of full frontal rigid barrier tests in this NCAP upgrade.

CHEST – NHTSA stated its intentions to conduct further research using the HIII-5F ATD with RibEye™ thoracic instrumentation in the December 2015 notice. The agency is including a report on that research in the docket containing this notice.[58] The agency is not planning to use the RibEye™ system with either the front or rear seat HIII-5F ATD based on the results of that report. The agency plans to evaluate the risk of chest injury to both the front and

[55] "Occupant Response Evaluation in NCAP Pilot Full Frontal Rigid Barrier Impact Crash Testing" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[56] "2014 Offset Frontal Collision Safety Performance Test Procedure" Japan NCAP. Accessed December 2016, available at http://www.nasva.go.jp/mamoru/en/download/other_download.html.
[57] SAE International Safety Test Instrumentation Standards Committee, "Test Device Head Contact Duration Analysis," SAE Standard J2052, Rev July 12, 2016, available at http://standards.sae.org/j2052_199003/.
[58] "Occupant Response Evaluation in NCAP Pilot Full Frontal Rigid Barrier Impact Crash Testing" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

rear seat HIII-5F using chest potentiometer data and the deflection formula listed in appendix III, which is identical to the formula presented in the December 2015 RFC Notice and the current NCAP.

ABDOMEN – The agency is seeking comment on including a submarining assessment for the rear seat HIII-5F ATD. Other consumer information programs such as Euro NCAP[59] and Japan NCAP[60] include an assessment of this phenomenon in their rating systems. In its research testing,[61] NHTSA observed two events that conformed to the criteria for submarining set forth in the Japan NCAP protocol. The agency is seeking comment on whether an assessment similar to this should be used to evaluate and potentially rate the performance of the rear seat HIII-5F in NCAP.

FEMUR – NHTSA plans to evaluate femur loading for the HIII-5F ATD seated in the front seat according to the formula in appendix III, which remains unchanged from the December 2015 RFC notice. The agency does not plan to evaluate femur loading for the HIII-5F ATD seated in the rear seat.

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[59] European New Car Assessment Programme, "Assessment Protocol – Adult Occupant Protection, Version 7.0.3, November 2015." Accessed December 2016, available at http://euroncap.blob.core.windows.net/media/20869/euro-ncap-assessment-protocol-aop-v703.pdf.

[60] "2014 Offset Frontal Collision Safety Performance Test Procedure" Japan NCAP. Accessed December 2016, available at http://www.nasva.go.jp/mamoru/en/download/other_download.html.

[61] "Occupant Response Evaluation in NCAP Pilot Full Frontal Rigid Barrier Impact Crash Testing" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

B. Side Crashworthiness

1. Side MDB Test

In the December 2015 RFC notice, the agency indicated that it would continue to conduct its current 61.9 km/h (38.5 mph) side MDB test, as 90-degree intersection-style crashes, which are represented by this side impact barrier test, are still a main source of injuries and fatalities in the field. As noted in appendix I, an analysis of the FARS data spanning calendar years 2010-2014 indicates that an estimated 1,983 fatalities in side impact vehicle-to-vehicle near side crashes occur annually. Ninety-four percent (1,859) of occupants in these crashes were seated in the front seat, and the remaining six percent (124) were seated in the rear.

The agency still intends to specify a WorldSID-50M ATD for use in the driver's seat instead of the 50^{th} percentile male ES-2re ATD, which is used currently. The agency believes the ES-2re dummy remains suitable for use in regulatory side impact tests because it provides the injury measures that are assessed in the current regulation. With the WorldSID-50M, NHTSA sees an opportunity at this time to incorporate into NCAP a crash test dummy representative of a 50^{th} percentile adult male that can more accurately assess thoracic injury under oblique loading conditions and better differentiate vehicle safety performance. In the future, the agency may consider amending Part 572 to include the WorldSID-50M. The SID-IIs 5^{th} percentile female dummy would continue to occupy the near-side rear outboard seat of the test vehicle, but would have added instrumentation. Comments are requested on this course of action.

2. Side Pole Test

The December 2015 RFC notice also presented NHTSA's plan to continue conducting the 32 km/h (20 mph) rigid pole side impact crash test currently covered under NCAP. NHTSA's real-world analysis, shown in appendix I, indicates that about 575 fatal side impact vehicle-to-pole crashes occurred annually. While the frequency with which side pole crashes occurred is low in comparison to vehicle-to-vehicle crashes, they still represent a significant number of fatalities, and so the agency still plans to include the side pole crash configuration in this NCAP upgrade. The agency reasons that, because these types of crashes tend to be very severe and introduce high levels of intrusion, changes made to improve performance in this crash mode should also serve to mitigate injuries in other crash configurations. The agency is also still considering the possibility of testing on the right sides of vehicles to ensure symmetry and equal performance given changes that may be made for the frontal oblique test.

As the agency believes it is advantageous to use the most advanced tools available, NHTSA is still tentatively planning to specify the WorldSID-50M ATD for use in the driver's seat in this test instead of the SID-IIs ATD, as is currently used in NCAP and under the FMVSS testing,[62] because, similar to that mentioned in the "Side MDB Test" section, the WorldSID-50M can more accurately assess injury risk in the oblique loading condition, particularly for the thoracic region. As will be discussed in the next section, the agency tentatively plans to use the WorldSID-50M equipped with the RibEye™ optical sensing system, as it has shown that it is capable of more accurately capturing maximum rib deflections, especially in oblique impacts, compared to the linear potentiometers used in the ES-2re and SID-IIs, or the WorldSID equipped with the standard 2D IR-TRACCs. Since both the ES-2re and the SID-IIs use unidirectional devices mounted at the lateral-most part of each rib to measure single-point rib deflections, both

[62] NHTSA recognizes that testing with the SID-IIs in the driver and the right front passenger position in the FMVSS No. 214 pole test is highly important to ensure side air bags protect a wide range of occupant sizes. For example, testing with the SID-IIs and a mid-size adult male ATD ensures that manufacturers design side curtain air bags large enough to protect both shorter drivers seated with the seat in its full frontal position, as well as mid-size occupants seated mid-track. NHTSA believes that use of the WorldSID-50M in the NCAP pole test would not reduce this need for the SID-IIs in FMVSS No. 214, but instead would enhance the baseline performance of the side air bag system required by FMVSS No. 214.

measure reduced deflections compared to the WorldSID-50M ATD with the RibEye™ system when subjected to oblique loading conditions, such as those represented by the agency's side NCAP pole test.

3. Side Test Dummies

a. WorldSID 50th Percentile Male ATD (WorldSID-50M)

i. WorldSID-50M Design

Although the agency stated that it planned to adopt the WorldSID-50M Standard Build Level F (SBL F) ATD in the December 2015 RFC notice, research conducted in the interim has prompted the agency to alter its original plan. The agency now tentatively plans to specify a WorldSID-50M dummy matching the drawings and parts list and meeting the qualification response corridors docketed with this notice for use in the side NCAP MDB and pole tests. This dummy will be equipped with the RibEye™ system in lieu of the standard 2D IR-TRACCs, which are currently utilized in the WorldSID-50M to measure rib deflections. NHTSA seeks comment on this plan.

A 2D IR-TRACC is comprised of an IR-TRACC, which is mounted between the spine box and the lateral-most part of a rib to measure the change in length between two points, and an optional rotary potentiometer, which tracks the rotation of the rib about the z-axis at the IR-TRACC location. A 2D IR-TRACC can be used to calculate the x- and y-components of the change in length between the lateral-most portion of a rib and the spine box. The RibEye™ system consists of two groups of three sensors (e.g., receivers) mounted on the impacted side of the spine box, one at each rib level, and three light emitting diodes (LEDs) per rib, mounted on the inner surface of the inner rib on the impact side. The RibEye™ system optically measures the change in distance in the x, y, and z directions between the spine box and three locations on each of the dummy's ribs.

These changes are planned because recent testing conducted using the RibEye™ system[63] has effectively shown the ability to capture chest deflection measurements at multiple locations on the ribs as compared to the single location measurement of the 2D IR-TRACCs. As will be discussed in detail later in this notice, research conducted by the agency showed that the RibEye™ system is durable and also better able to capture oblique loading than the IR-TRACC system. In light of these findings, the agency currently plans to use the RibEye™ system, in lieu of the 2D IR-TRACCs, to measure shoulder, thoracic, and abdominal rib deflections. The agency is requesting comment on the use of the RibEye™ system for the WorldSID-50M.

ii. Biofidelity

Although the biofidelity rankings, discussed in the December 2015 RFC, were assessed several years ago, the dummy design, with the exception of incorporation of the RibEye™ system, has not changed significantly since then. Since the IR-TRACC components were equivalent in mass to those of the RibEye™ system and the center of gravity was maintained, the agency does not believe that another biofidelity assessment is necessary for this dummy.

iii. WorldSID-50M with RibEye™

The agency conducted research to evaluate the use of RibEye™ optical sensors in the WorldSID-50M ATD's shoulder, thorax, and abdomen in lieu of the 2D IR-TRACCs. In order to determine the optimal locations of the RibEye™ sensors,[64] dynamic impact tests were performed

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[63] Hardware User Manual, RibEye multi-point deflection measurement system, 3-axis version for the WorldSID 50th Male ATD, Boxboro Systems, LLC, December 2016, available at http://www.boxborosystems.com/.

[64] The testing for determination of the final locations of the RibEye™ sensors can be found in the "Implementation of RibEye™ in the WorldSID 50th Percentile Male Dummy" report in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

on single thoracic ribs of the WorldSID-50M at multiple angles anterior-to-lateral and posterior-to-lateral, as well as purely lateral. For the tests conducted, the maximum and mean errors for the final LED locations for the RibEye™ system were found to be much less than those for the WorldSID-50M's 2D IR-TRACC location. Therefore, the agency currently believes that the use of the RibEye™ system in the WorldSID-50M should produce more accurate deflection readings than the 2D IR-TRACC system with regard to measuring the true maximum deflection that occurs at any location.[65] The final LED locations were utilized in subsequent testing (sled and crash) to evaluate the feasibility of the RibEye™ in the WorldSID-50M ATD.

The agency conducted a series of 13 sled tests using the RibEye™ system in the WorldSID-50M ATD in six different test conditions.[66] As all of the sled test conditions were lateral impacts, the objective of these tests was not to determine the advantage of using RibEye™ over 2D IR-TRACCs but rather to establish the usability of RibEye™ in a full-dummy dynamic test condition. The RibEye™ showed comparable measurements to a chest band wrapped around the rib, the RibEye™ LEDs followed the contour of the inner rib, and the RibEye™ system captured the maximum deflection of the inner rib at the location of the most loading. The RibEye™ system was effective at measuring maximum deflection during the sled tests; however, some instances of signal blockage indicated that the RibEye™ cable routing needs to be improved so that the cables are not able to obstruct the path of light between the sensors and LEDs. The agency plans to optimize cable routing for future testing.

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[65] The agency does not mean to infer that the IR-TRACCs are not accurate; they do measure accurately at the one point where they are located. However, in terms of measuring the true maximum deflection of the rib, the RibEye™ system is more accurate because it measures more than one point and has a better chance of capturing the maximum deflection.

[66] See "Evaluation of RibEye™ Installed in the WorldSID 50th Percentile Male Dummy" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

As will also be discussed in the Validation Testing section of this notice, the agency also conducted 12 full-scale side impact crash tests (six side MDB and six side pole) to evaluate crash injury measures from the WorldSID-50M with the RibEye™ system.[67] To provide information for assessing the effectiveness of the RibEye™, a chest band was installed on the upper thoracic rib to illustrate its shape during the crash tests. The chest band contours showed that not only did the RibEye™ LEDs follow the behavior of the rib deformation, but they also revealed that anterior oblique loading occurred in many of the oblique pole tests and posterior oblique loading occurred in some of the MDB tests. These findings suggest that it is advantageous to measure multiple points of deflection in order to capture chest deflection in anterior-to-lateral, posterior-to-lateral and lateral directions in NCAP's side impact crash tests.[68] In fact, this was exemplified by thoracic rib deflection readings recorded in three additional side pole crash tests conducted with the ES-2re. As shown in table 2 of appendix XIII, these tests showed much higher thoracic rib deflection readings for the WorldSID-50M compared to the ES-2re for the same vehicle make and model, which is consistent with the WorldSID-50M with RibEye™ being more capable of capturing oblique loading.[69]

In light of these findings, the agency currently believes that the RibEye™ system provides benefit over the IR-TRACC during oblique loading and plans to use the WorldSID-50M with RibEye™ in NCAP side impact pole and MDB crash tests. Comments are requested on whether NHTSA should use the RibEye™ system instead of the 2D IR-TRACCs in NCAP.

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[67] See "Evaluation of RibEye™ Installed in the WorldSID 50th Percentile Male Dummy," and "Side Impact Crash Tests Using the WorldSID and SID-IIs Anthropomorphic Test Devices (ATDs)" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[68] See "Side Impact Crash Tests Using the WorldSID and SID-IIs Anthropomorphic Test Devices (ATDs)" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[69] The WorldSID-50M also measured greater thoracic rib deflections as compared to the SID-IIs when subjected to the same test conditions, as shown in table 2 of appendix XIII.

iv. Repeatability and Reproducibility

As mentioned in the December 2015 RFC notice, the WorldSID-50M ATD's body regions demonstrated good repeatability and reproducibility (R&R) when the dummy was subjected to qualification tests performed per ISO 15830-2.[70] The resulting coefficient of variation (CV)[71] for the dummy's various body parts was below 5 percent in many cases and below 10 percent in all measured cases, with the exception of lower spine T12 lateral acceleration when the dummy's thorax was assessed without the arm.[72] Responses having a CV of less than 5 percent are considered as having an "excellent" level of repeatability, while those having a CV of less than 10 percent (but greater than 5 percent) are considered "good" to "marginal."[73] WorldSID-50M R&R was generally better than that for the ES-2re, although, as noted above with regard to THOR, comparing R&R across dummies is not necessary when both dummies are deemed acceptable for a testing program.

The agency conducted additional tests to assess R&R for the WorldSID-50M. Details of this testing can be found in the "Evaluation of the WorldSID 50th Percentile Male Side Impact Dummy Qualification and Sled Test Repeatability and Reproducibility" report, docketed concurrently with this notice.[74] Sled testing, which was performed prior to the completion of NHTSA's research on the RibEye™ system, was conducted using WorldSID-50M ATDs fitted with 2D IR-TRACC instrumentation. Qualification tests, on the other hand, were performed for

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[70] Scherer, R., Bortenschlager, K., Akiyama, A., Tylko, S., Hartleib, M., & Harigae, T., "WorldSID Production Dummy Biomechanical Responses," The 21st International Technical Conference for the Enhanced Safety of Vehicles Conference, Paper No. 09-0505, 2009, available at http://www-nrd.nhtsa.dot.gov/pdf/esv/esv21/09-0505.pdf.
[71] The coefficient of variation is a measure of the variability expressed as a percentage of the mean.
[72] For this test, the CV was 10.7 percent.
[73] Responses with a CV of 5 to ≤ 8 are considered as having "good" R&R, and responses with a CV of 8 to ≤ 10 are considered as having "marginal" R&R, in addition, responses with a CV of more than 10 percent are generally considered as having "unacceptable" or "poor" repeatability.
[74] Located in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

WorldSID-50M ATDs instrumented with RibEye™.[75] The agency decided not to repeat the sled tests for ATDs equipped with RibEye™ because the qualification test data did not indicate that torso responses changed when the 2D IR-TRACC was replaced with the RibEye™ system.[76] For this reason, results from both test series are discussed below.

The rigid flat wall and padded wall sled tests conducted by the agency to assess R&R for the WorldSID-50M were performed in accordance with four test protocols. The dummies generally exhibited "excellent" or "good" repeatability for the sled test conditions. However, "marginal" and "poor" results were observed in a few instances, particularly those where the measured values were very low. On occasions where this was not the case, the fact that the sled impact wall did not extend vertically to the shoulder level and the ATDs' heads were not restrained, may have also contributed to higher CV values. Furthermore, the agency believes that padding characteristics may have also introduced additional sources of variation in padded wall tests.

The R&R qualification testing conducted by the agency for the WorldSID-50M dummy with RibEye™ was performed using the procedures specified in the "WorldSID 50th Percentile Male (WorldSID-50M) Qualification Procedures Manual," docketed concurrently with this notice.[77] The test conditions included head drop tests, neck pendulum tests, shoulder impacts, thorax (with and without arm impacts), abdomen impacts, and pelvis impacts.[78] This testing

[75] As will be detailed in the Durability section of this notice, modifications to the rib damping material and pelvis data acquisition system (DAS) docking station were implemented for all dummies to address durability issues.
[76] See "Evaluation of the WorldSID 50th Percentile Male Side Impact Dummy Qualification and Sled Test Repeatability and Reproducibility" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?ID=NHTSA-2015-0119.
[77] See "WorldSID 50th Percentile Male (WorldSID-50M) Qualification Procedures Manual" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?ID=NHTSA-2015-0119.
[78] Due to time constraints, the R&R qualification tests for the shoulder, thorax (with and without arm), abdomen, and pelvis were only performed on the dummies' left side, whereas head drop and neck pendulum tests were conducted for both the left and right side.

showed "excellent" or "good" repeatability for almost all measures and generally "excellent" or "good" reproducibility. These results suggest that the WorldSID-50M with RibEye™ exhibits an acceptable level of R&R for use in the upgraded program.

v. Seating procedure

An updated seating procedure for the WorldSID-50M ATD (WS-50M) has been developed to replace the previous seating procedure (WS-50M RFC) that was included in the December 2015 RFC notice. Since the THOR-50M and the WorldSID-50M are built based on the same anthropometry study, the WS-50M RFC seating procedure was revised to reflect improvements identified during the development of the THOR-50M procedure. This update was made to provide consistency between seating procedures for the two new advanced 50th percentile dummies (THOR-50M and WorldSID-50M) planned for this program upgrade.

The agency performed a study on six vehicles to compare the WorldSID-50M dummy positions using both the WS-50M RFC and updated WS-50M seating procedures. The results of this study seem to confirm that the THOR-50M seating procedure was generally adaptable for the WorldSID-50M with some minor modifications. The agency seeks comment on this conclusion. The primary differences between the WS-50M RFC and updated WS-50M procedures were: (1) final seat placement in relationship to mid-track, (2) foot placement, and (3) seat back or head restraint adjustment.[79]

vi. Validation Testing

Twelve full-scale side impact crash tests were conducted to aid in developing the basis for a rating system in support of this RFC notice. Six MY 2015-2016 vehicles were chosen for evaluation, and each vehicle underwent side MDB and oblique pole crash tests with the

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[79] See "WorldSID Seating Procedure Evaluation" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

WorldSID-50M and SID-IIs ATDs, as appropriate, in accordance with the planned test protocols.[80] The WorldSID-50M ATD was positioned in the vehicles using the updated WS-50M seating procedure referenced in the previous section.

Per the agency's plan, shoulder, thoracic, and abdominal rib deflections in the WorldSID-50M were measured using the RibEye™ system rather than 2D IR-TRACCs. As explained in detail in the "Evaluation of RibEye™ Installed in the WorldSID 50th Percentile Male Dummy" report, docketed concurrently with this notice, and noted previously in the WorldSID-50M with RibEye™ section, the RibEye™ system successfully captured the maximum rib deflections for the shoulder, thorax, and abdomen body regions in this series of oblique pole and MDB tests.

Summary tables of results can be seen in appendices IX-XI as well as in the validation testing report docketed concurrently with this notice.[81] Results from this testing with the WorldSID-50M were compared to readings obtained in previous NCAP side MDB crash tests with the ES-2re (See table 1 of appendix XIII.) This comparison showed that the majority of injury values recorded for the ES-2re were generally higher compared to the WorldSID-50M in the MDB tests. This was true for all body regions.

The agency currently believes there are several reasons why measured thoracic and abdominal rib deflections differ between the ES-2re ATD and the WorldSID-50M ATD equipped with RibEye™ in these tests. As mentioned in the December 2015 RFC notice, differences in physical design, biofidelity, and seating procedures exist for the two dummies. It should also be noted that even though higher thoracic deflections were observed for the ES-2re ATD compared to the WorldSID-50M ATD, the deflections were low (<25 millimeters (mm))

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[80] These six vehicles were also chosen for full frontal, frontal oblique, and crashworthiness pedestrian testing.
[81] See "Side Impact Crash Tests Using the WorldSID and SID-IIs Anthropomorphic Test Devices (ATDs)" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

and may not be significant as such values would translate to very low levels of thoracic injury risk for an occupant.[82] Despite these findings, the agency believes that the WorldSID-50M with RibEye™ is more suitable for inclusion in NCAP tests because of its expanded measurement capabilities.

The agency believes that the multi-point RibEye™ system used in the WorldSID-50M captures rib deflections more effectively than the single-point linear potentiometers used in the ES-2re and SID-IIs dummies, particularly for oblique loading conditions such as those seen in the agency's side pole test. As mentioned previously, in a series of pole tests conducted by the agency, chest bands placed around the WorldSID-50M ATD's first thoracic rib (e.g., the rib that measured the highest deflections for both dummies) confirmed that the RibEye™ LEDs captured the behavior of the rib deformation. Additionally, NHTSA saw much higher deflections for the WorldSID-50M compared to the ES-2re in these test conditions.

vii. Durability

The agency conducted a series of qualification tests (head drop tests, neck and lumbar spine pendulum tests, and full-body impact tests) at increasing energy levels to assess the durability of the WorldSID-50M ATD with RibEye™.[83] Energy levels were increased 10 percent, 20 percent, and 30 percent above baseline qualification test energy levels. Similar to that observed in earlier testing, the qualification durability testing also revealed very minor delamination on the Shoulder Rib and Thorax Rib 1.[84] This delamination did not worsen over the course of the testing series and could only be observed when the ribs were slightly flexed. These

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[82] A measurement of 25 mm of deflection corresponds to approximately 0 percent chance of thoracic injury for a 45-year-old based on a Weibull curve, and 10 percent chance of thoracic injury for a 67-year-old based on a log-logistic curve.
[83] See "WorldSID-50th Durability Report" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[84] 80 FR 78541.

findings prompted a change in the manufacturing process that was intended to improve the bonding strength between the damping material and the steel rib band. The agency also observed tears in the thorax pad after abdominal impacts. Similar tears have been reported by others and, as a result, the thorax pad has undergone a redesign to minimize the number of times the foam pad would have to be replaced. The original one-part pad would be comprised of two parts: one part to cover the abdominal ribs and another to cover the thoracic ribs.

Durability was also assessed during sled testing as well as during full-scale crash testing. As with the qualification series, minor shoulder rib delamination was observed during crash testing. Additionally, damage to the sacroiliac load cell was observed after a crash test. An inspection of the pelvic region indicated that the large hex cap screw which retains the hip joint socket in the pelvic bone may have contacted the load cell interface due to a large amount of deflection. This damage was not seen in qualification or crash testing.

In particular, it is worth noting that damage to the RibEye™ system was not found in any of the three test conditions. This represents an improvement with regard to durability over the 2D IR-TRACC system for the WorldSID-50M ATD.[85] As noted in the December 2015 RFC notice, previous test series conducted by the agency had revealed durability concerns with the WorldSID-50M shoulder IR-TRACC, albeit minor ones revealed during severe loading conditions.[86] Furthermore, the RibEye™ system performed as expected in this testing, as it captured peak rib deflections.

Overall, the durability of the WorldSID-50M ATD with RibEye™ was found to be good, even when qualification test input energy was increased up to 30 percent. The durability of the

[85] As noted in the December 2015 RFC notice, previous test series conducted by the agency revealed durability concerns with the WorldSID-50M shoulder IR-TRACC, albeit minor ones revealed during severe loading conditions.
[86] 80 FR 78541.

WorldSID-50M ATD is comparable to that of the ES-2re currently used in NCAP. Further information regarding durability can be found in the "WorldSID-50th Durability Report," docketed with this notice.[87]

viii. Injury Criteria and Risk Curves

The agency outlined its preliminary injury criteria for the WorldSID-50M ATD for incorporation into this NCAP upgrade in the December 2015 RFC notice. These criteria, developed in 2012 by Petitjean et al.,[88] were generally consistent with those recommended by ISO/TC22/SC12/WG6 and those currently under evaluation by the Working Party on Passive Safety (GRSP) for inclusion in the pole side impact global technical regulation (PSI-GTR). With a few exceptions, they are also used currently by the Euro NCAP for rating vehicles. Although the agency has chosen to retain several of these criteria in this notice, some are no longer being considered for inclusion, and others have been modified or added in light of research recently conducted. All updates are summarized in the sections below, and these new or revised injury criteria are further detailed in an injury criteria report for the WorldSID-50M, which is included in the docket for this notice.[89] For this NCAP upgrade, the agency is considering the use of WorldSID-50M risk curves, presented in appendix IV, to set lower and upper performance limits for each injury criterion. These lower and upper limits are used to set the boundaries for the linear scale, points-based rating calculation, which is used to determine the crashworthiness ratings that will be presented later in the document.

The agency is now requesting comment on the following criteria:

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[87] See "WorldSID-50th Durability Report" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

[88] Petitjean, A., Trosseille, X., Praxl, N., Hynd, D., Irwin, A., "Injury Risk Curves for the WorldSID 50th Male Dummy," Stapp Car Crash Journal, 56: 323–347, 2012.

[89] See "WorldSID 50th Percentile Male Side Impact Dummy Injury Risk Functions for the New Car Assessment Program (NCAP)" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

HEAD – As previously planned, the agency is considering adopting two injury criteria to address head injuries in side NCAP crash tests: the head injury criterion, HIC, to address head injuries induced by translational head acceleration, and the brain injury criterion, BrIC, to address brain injuries stemming from rotational motion of the head.

a. HIC

Although the agency stated in the December 2015 RFC notice that it planned to adopt HIC of a 36-millisecond duration for the WorldSID-50M, the agency now plans to adopt HIC of a 15-millisecond duration (HIC_{15}) for this dummy in NCAP. The agency tentatively believes that deviating from the head injury criterion used currently in NCAP's side program and in FMVSS No. 214 for the ES-2re and SID-IIs dummies would be warranted because: (1) it aligns with the head injury criterion used for frontal NCAP, Euro NCAP, the Insurance Institute for Highway Safety (IIHS), and FMVSS No. 208, and (2) HIC_{15} better correlates to PMHS experimental data on skull fractures used to develop HIC. [90, 91] This experimental data consisted primarily of PMHS head drops to rigid surfaces that produced short-duration impacts (1 to 10 milliseconds (ms) in duration). Eppinger et al. (1999) noted that, "in the original biomechanical skull fracture data from which HIC was derived, no specimen experienced a skull fracture and/or brain damage with a HIC duration greater than 13 ms." Because the agency will now be assessing brain injury with BrIC, the agency believes that assessing skull fracture using HIC_{15} is the most complementary approach.

b. BrIC

[90] Eppinger, R., Sun, E., Bandak, F., Haffner, M.,Khaewpong, N., Maltese, M., & Saul, R.,''Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems II,'' NHTSA Docket No. NHTSA–1999–6407–5, 1999.

[91] See "Injury Criteria for the THOR 50th Male ATD" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

As mentioned in the frontal impact sections of this notice, the agency plans to use the same formulation for BrIC that was given in the December 2015 RFC notice. As with the THOR-50M and HIII-5F dummies, BrIC will be assessed at the AIS 4+ level. The BrIC injury risk curve is included, along with the AIS3+ risk curve associated with HIC_{15}, in appendix IV of this notice for the WorldSID-50M. Details surrounding the development of the BrIC risk curve can be found in a report included in the docket for this notice.[92]

SHOULDER – In the December 2015 RFC notice, NHTSA expressed its intent to evaluate shoulder injury risk for the WorldSID-50M ATD as a function of maximum shoulder force in the lateral direction (Y-axis) and provided an AIS 2+ risk curve, developed by Petitjean et al., for this purpose.[93] The agency also requested comment on the merits of alternatively adopting a performance criterion limit, or injury assessment reference value (IARV), of 3.0 kN for the NCAP ratings in lieu of the AIS 2+ risk curve for shoulder force. This limit, which seemed reasonable given results from the agency's fleet testing at the time, was adopted by the side pole GTR informal working group to prevent vehicle manufacturers from using excessive shoulder loading to reduce thorax loading artificially.[94] The agency had some concern that, by assessing shoulder injury as a function of risk, it might hinder manufacturers from providing the most effective protection for the thorax. As this concern has not been allayed since the publication of the December 2015 RFC notice, the agency plans to adopt only an upper performance limit for shoulder force at this time.

a. Shoulder Force

[92] Ibid.
[93] Petitjean, A., Trosseille, X., Praxl, N., Hynd, D., Irwin, A., "Injury Risk Curves for the WorldSID 50th Male Dummy," Stapp Car Crash Journal, 56: 323-347, 2012.
[94] The agency's fleet testing at that time showed maximum shoulder forces ranging from 1.2 kN to 2.6 kN for oblique pole tests and 876 N to 2.3 kN in the side impact MDB tests.

As the shoulder's tolerance to peak force is greater than that of the thoracic region, it is advantageous to allow manufacturers to distribute the crash load across the portions of the body more able to withstand the loading. Furthermore, this is in line with practices adopted by Euro NCAP and the side pole GTR working group.[95] However, given the range of shoulder forces recorded for the WorldSID-50M in the agency's validation tests, the agency has chosen to adopt a lower performance limit than the 3.0 kN limit used by Euro NCAP and the side pole GTR working group. This will be further discussed in the ratings section of this notice.

b. Shoulder Deflection

In addition to maximum shoulder force, NHTSA requested comment on the merits of also adopting a risk curve, developed by ISO/TC22/SC12/WG, for AIS 2+ shoulder injury that is a function of shoulder deflection. This risk curve was developed using maximum shoulder rib IR-TRACC deflection as the independent variable to correlate with PMHS shoulder injuries. Because the RibEye™ system is being used in place of the IR-TRACC for shoulder rib deflection, it was necessary for the agency to repeat the sled and impactor tests performed previously by Petitjean et al. for the WorldSID-50M equipped with RibEye™.[96] Details regarding this testing and the subsequent injury risk function development can be found in the "WorldSID 50th Percentile Male Side Impact Dummy Injury Risk Functions for the New Car Assessment Program (NCAP)" report, docketed with this notice.[97] The maximum shoulder rib (with RibEye™) deflections measured for these tests were correlated to PMHS shoulder injuries

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[95] European New Car Assessment Programme, "Assessment Protocol – Adult Occupant Protection." Accessed July 2016, available at http://euroncap.blob.core.windows.net/media/20869/euro-ncap-assessment-protocol-aop-v703.pdf.

[96] Petitjean, A., Trosseille, X., Praxl, N., Hynd, D., Irwin, A., "Injury Risk Curves for the WorldSID 50th Male Dummy," Stapp Car Crash Journal, 56: 323-347, 2012.

[97] See "WorldSID 50th Percentile Male Side Impact Dummy Injury Risk Functions for the New Car Assessment Program (NCAP)" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

with PMHS age serving as a covariate to account for fragility. As noted in the aforementioned report, the agency concluded that the relationship between the WorldSID RibEye™ shoulder deflection and the PMHS injury data for the same conditions was not statistically significant. In light of these findings, the agency has decided not to proceed with adopting a risk curve for shoulder deflection at this time.

CHEST – NHTSA announced in the December 2015 RFC notice its intention to adopt a metric to assess the risk of chest injury in side impact crashes. At that time, the agency considered adopting the injury risk function, developed by Petitjean et al., to relate the maximum thoracic and abdominal rib deflection, as measured by 1D IR-TRACCs in the WorldSID-50M, to AIS 3+ thoracic skeletal (and abdominal skeletal) injury observed in PMHS.[98,99] However, because of conflicting research, the agency was unsure whether the WorldSID-50M with 1D IR-TRACCs, or even 2D IR-TRACCs, would accurately measure deflections under oblique loading conditions.[100]

The agency noted in the December 2015 RFC notice that it was in the process of conducting research with the WorldSID-50M ATD using the optical sensing system, RibEye™. This research demonstrated that RibEye™ is more likely than the 1D or 2D IR-TRACC to detect the maximum deflection experienced by the WorldSID thorax, particularly under oblique loading conditions.[101] Given these findings, it was necessary to repeat the impactor and sled tests used by Petitjean et al. to develop the skeletal injury risk function for thoracic and abdominal rib

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[98] Petitjean, A., Trosseille, X., Praxl, N., Hynd, D., Irwin, A., "Injury Risk Curves for the WorldSID 50th Male Dummy," Stapp Car Crash Journal, 56: 323-347, 2012.
[99] The agency noted that this risk curve was a function of both thoracic and abdominal rib deflection because the WorldSID-50M ATD's abdominal ribs partially overlap the thorax ribs for a mid-size male. Therefore, increased loading of the WorldSID-50M ATD's abdominal ribs would be expected to increase the risk of both abdominal and thoracic injuries.
[100] 80 FR 78544.
[101] See "Evaluation of RibEye™ Installed in the WorldSID 50th Percentile Male Dummy" report in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

deflection (as measured by a 1D IR-TRACC) for the WorldSID-50M, for the same dummy equipped with RibEye™. The maximum reading from the thoracic and abdominal rib RibEye™ deflections recorded for each test was correlated to both skeletal and soft tissue injuries from the PMHS thorax. Details regarding this testing and the subsequent development of injury risk functions can be found in the "WorldSID 50th Percentile Male Side Impact Dummy Injury Risk Functions for the New Car Assessment Program (NCAP)" report, docketed concurrently with this notice.[102]

Although acceptable correlations were found for both AIS 3+ and 4+ severity levels, the agency has chosen to adopt the AIS 3+ function to assess skeletal injury risk for the WorldSID-50M equipped with RibEye™. Not only will the use of the AIS 3+ function mitigate a broader range of injury severity, but, similar to that noted for other injury criteria sections, the AIS 3+ function permits the maximum differentiation of the validation test data. In the agency's validation test series, deflection readings ranged from a minimum of 7 mm to a maximum of 61 mm in the side pole and MDB tests. For the AIS 3+ curve scaled for a 45-year-old, these values correspond to 0 percent and 64 percent risk, respectively. For the AIS 4+ curve, both values translate to 0 percent risk for a 45-year-old. Only the AIS 3+ curve permits adequate discrimination for the validation test data. This is true regardless of the age the risk curves are scaled to.

For the AIS 3+ severity level, the RibEye™-based function becomes progressively more stringent than the 1D IR-TRACC-based function as age increases. As will be explained further in the rating system section of this notice, this stringency for the 67-year-old curve has prompted the agency to use the 67-year-old AIS 3+ risk curve, at this time, to base the lower performance

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[102] See "WorldSID 50th Percentile Male Side Impact Dummy Injury Risk Functions for the New Car Assessment Program (NCAP)" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

limits for RibEye™-based thoracic skeletal deflection, and the corresponding 45-year-old risk curve to base the upper performance limits for this criterion. By using a more stringent risk curve for the lower performance limit, NHTSA can encourage a higher level of protection for all occupants. The agency notes that this is a similar approach to that taken by Euro NCAP for its side impact tests. Furthermore, given the range in thoracic and abdomen rib RibEye™ deflection readings recorded during the agency's validation tests, NHTSA tentatively believes that the 45-year-old curve is the most viable option to use for the upper performance limit to differentiate vehicle performance and incentivize improvements. At the AIS 3+ severity level, the maximum recorded deflection, 61 mm, corresponds to 64 percent risk for a 45-year-old, as mentioned previously, and 97 percent risk for a 67-year-old.

The agency acknowledges that the thoracic and abdominal rib deflection readings recorded for the WorldSID-50M during the side MDB validation tests were very low compared to those for the side pole tests. Nonetheless, the agency believes that it should retain a criterion aimed at assessing skeletal thoracic injury in the ratings for both side tests in order to ensure that vehicle manufacturers continue to provide adequate side torso protection in vehicle-to-vehicle crashes. Although the agency recognizes that vehicles are required to provide a minimum level of thoracic protection to comply with FMVSS No. 214 using the ES-2re dummy, the agency believes that it is also important for NCAP to assess such injuries with the WorldSID-50M because: (1) the side MDB NCAP test is performed at a higher speed (38.5 mph (62 km/h)) compared to FMVSS No. 214 (33.5 mph (54 km/h)) and is, therefore, potentially more injurious; (2) including a thoracic injury criterion in the new NCAP ratings program should encourage vehicle manufacturers to strive to reduce thoracic injury risk, and not just comply with minimum thresholds; and (3) the WorldSID-50M has increased biofidelity, meaning that it more accurately reflects human injuries. The agency notes that the ES-2re dummy remains appropriate for regulatory use because it provides the injury measures that are assessed in current regulations.

ABDOMEN – As mentioned in the preceding section, the agency plans to adopt a rib deflection criterion to assess both thoracic and abdominal skeletal injuries. In addition to this criterion, the agency also stated its intention in the December 2015 RFC notice to adopt an abdominal rib deflection injury criterion for the WorldSID-50M ATD to gauge abdominal soft tissue injury risk. At the time of that notice, the agency included a risk curve for AIS 2+ abdomen soft tissue injury for the WorldSID-50M as a function of maximum abdomen rib deflection measured by the 1D IR-TRACCs. However, since the agency's research has shown that RibEye™ is much more likely than the 1D IR-TRACCs to capture maximum thoracic and abdominal rib deflections, particularly under oblique loading conditions, the agency tentatively believes that there is merit to adopting a RibEye™-based risk function for abdominal soft tissue injuries instead of that developed for the 1D IR-TRACCs.

Since the December 2015 RFC notice, the agency has worked to construct AIS 2+ and 3+ risk curves for abdominal soft tissue injury risk for the WorldSID-50M equipped with RibEye™. This dummy was tested in the same sled test configurations used by Petitjean et al. to develop a risk function for abdominal soft tissue injuries as measured by the maximum abdomen rib deflection from the 1D IR-TRACC. Details on the development of the abdominal soft tissue injury risk curve can be found in the injury risk function development report, docketed with this notice.[103] The agency plans to assess soft tissue abdominal injuries at the AIS 2+ severity level because no distribution was found to be acceptable at the AIS 3+ level.[104]

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[103] See "WorldSID 50th Percentile Male Side Impact Dummy Injury Risk Functions for the New Car Assessment Program (NCAP)" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[104] None of the AIS 3+ abdomen soft tissue injury risk functions had a p-value less than 0.05.

The agency found that, at the AIS 2+ severity level, the RibEye™-based function is generally more stringent than the 1D IR-TRACC-based function, particularly at higher risk levels. However, this comparative stringency is progressively reduced as age increases. Regardless, the agency plans to consider the 67-year-old AIS 2+ risk curve because it is the most stringent for this age. Furthermore, given the range in abdomen rib deflection readings recorded during the agency's validation tests, NHTSA tentatively believes that it is the most viable option to use to differentiate vehicle performance and incentivize improvements. The maximum abdominal rib deflection reading recorded in the agency's side MDB and side pole testing was 45 mm. At the AIS 2+ severity level, 45 mm of deflection corresponds to 0 percent risk for a 45-year-old and 17 percent risk for a 67-year-old. The limit that the agency is considering for this criterion is presented later in this document.

LOWER SPINE – The agency requested comment in the December 2015 RFC notice on whether to adopt a criterion aimed at addressing resultant lower spine (T12) acceleration. This criterion was considered because: (1) resultant spinal acceleration is thought to provide a good measure of the overall loading on the thorax since it is derived from tri-axial accelerometers (x, y, and z direction), thus making it less sensitive to the direction of impact,[105] and (2) the ISO informal working group adopted a 75 g limit (except for intervals whose cumulative duration is not more than 3 ms) for lower spine acceleration for the side pole GTR.

However, at this time, the agency has no further plans to incorporate this criterion into the new NCAP in tests incorporating the WorldSID-50M. As mentioned previously, with respect to lower spine (T12) acceleration, the agency's thorax without arm qualification tests showed only marginal repeatability for one dummy, and marginal reproducibility for the three dummies

[105]Kuppa, S. "Injury Criteria for Side Impact Dummies," National Highway Traffic Safety Administration, January 2006, in NHTSA-2015-0119, available at https://www.regulations.gov/document?D=NHTSA-2015-0119-0011.

assessed. Furthermore, as the agency now plans to use the WorldSID-50M equipped with RibEye™ instead of the IR-TRACCs, the RibEye™ system will more effectively capture forward or rearward rotation of the ribs that results from severe lower thorax or abdomen oblique loading. As will be discussed in the following section, the agency also plans to measure resultant sacroiliac force to ensure that oblique loading which would be recorded by the lower spine (T12) is captured.

PELVIS – The WorldSID-50M ATD is capable of measuring posterior sacroiliac loads and anterior pubic symphysis loads in addition to lateral pelvis acceleration. In the December 2015 RFC notice, NHTSA stated its intention to adopt an injury risk curve to relate the measured maximum pubic symphysis force to the risk of an AIS 2+ pelvis injury. At the time, the agency expressed that it would not similarly adopt criteria aimed at assessing pelvis injuries stemming from sacroiliac loads because a risk curve for the posterior pelvis was not yet developed for the WorldSID-50M. Citing field evidence, however, that suggested that posterior pelvic injury may not be detected by the pubic symphysis load cell, the agency requested comment on how the pubic symphysis and sacroiliac loads interrelate and whether it is possible and necessary to establish injury criteria for both pelvic regions.

a. Pubic Symphysis Force

At this time, the agency still plans to adopt the AIS 2+ risk curve for pubic symphysis force, developed by Petitjean et al.[106] To assist the public in formulating comments, this risk curve is again cited in appendix IV of this notice.

Although Petitjean et al. provided risk curves for pubic symphysis force that were adjusted to represent a 45-year-old and a 67-year-old, the agency plans to adopt the risk curve for

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[106] Petitjean, A., Trosseille, X., Praxl, N., Hynd, D., Irwin, A., "Injury Risk Curves for the WorldSID 50th Male Dummy," Stapp Car Crash Journal, 56: 323-347, 2012.

a 67-year-old at this time. The agency believes that this curve is the most appropriate because Petitjean et al. indicated that the quality index would be the best for the 67-year-old curves since that was the median age of the PMHS included in the samples studied.[107,108]

Furthermore, although the agency requested comments on the merits of alternatively adopting the AIS 3+ risk curve for pubic symphysis force developed by Petitjean et al, in lieu of the AIS 2+ curve, the agency has since determined that it is most appropriate to use the AIS 2+ curve for a 67-year-old. The agency believes that it is necessary to adopt the AIS 2+ curve because the AIS 3+ risk curve may not permit adequate differentiation between vehicles. The maximum readings for pubic force recorded during the side NCAP MDB and pole validation tests were 1.33 kN and 1.51 kN, respectively, which translates to less than five percent chance of AIS 3+ injury for the driver in each test. Adopting the AIS 2+ curve instead of the AIS 3+ curve also allows the agency to protect against less serious injuries.

b. Sacroiliac Force

At this time, the agency also plans to adopt an injury criterion to assess AIS 2+ resultant sacroiliac forces for the WorldSID-50M ATD. The agency believes that it is important to measure both the anterior (e.g., pubic) and posterior (e.g., sacroiliac) pelvis loads to ensure that manufacturers will not concentrate all loading to the posterior portion of the pelvis to minimize pubic forces. Consequently, the agency reasons it is necessary to add a criterion to assess sacroiliac injuries in addition to injuries to the pubic symphysis.

Since a risk function for sacroiliac force was not developed, the agency formulated one for this NCAP upgrade. NHTSA tested the WorldSID-50M in the same impactor and sled test

[107] Ibid.
[108] The quality index is related to the size of the confidence interval for a risk curve. The higher the quality index, the narrower the confidence interval, meaning the selected risk function is a better representation of the relationship between the WorldSID data and PMHS injury presence.

configurations used by Petitjean et al. to develop the risk curves for pubic force.[109] Details regarding this testing and the subsequent injury risk function development can be found in the "WorldSID 50th Percentile Male Side Impact Dummy Injury Risk Functions for the New Car Assessment Program (NCAP)" report, docketed with this notice.[110]

Risk curves for the posterior pelvis were constructed to correlate both lateral (Y-axis) force and resultant (XYZ-axes) force to pelvic injuries observed in the PMHS tests. The agency plans to adopt the injury risk function relating to resultant sacroiliac force, instead of simply lateral force, in an effort to capture off-axis loading occurring at the pelvis's posterior and address scenarios where the injury mechanism for the sacroiliac joint may not solely be a result of pure lateral loading.

With respect to the severity level and age chosen, the agency has made similar decisions for the sacroiliac force to those made for the pubic symphysis force. The agency plans to proceed with using an AIS 2+ risk curve developed for a 67-year-old to set lower and upper limits. This risk curve is included in appendix IV for the WorldSID-50M.

Since the agency used the same PMHS injury data set (where the median age was 67-years-old) to develop the risk curves for sacroiliac force that Petitjean et al. employed to construct the pubic symphysis force risk curves, the agency believes that the 67-year-old risk function similarly better represents the relationship between the WorldSID-50M test data and the presence of PMHS injury for this age. With respect to the severity level selected, the agency has concluded that the AIS 2+ curve is statistically more relevant, and therefore, a more appropriate

[109] Petitjean, A., Trosseille, X., Praxl, N., Hynd, D., Irwin, A., "Injury Risk Curves for the WorldSID 50th Male Dummy," Stapp Car Crash Journal, 56: 323-347, 2012.
[110] See "WorldSID 50th Percentile Male Side Impact Dummy Injury Risk Functions for the New Car Assessment Program (NCAP)" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

choice.[111] This also allows the agency to align with the severity level chosen for the pubic symphysis force and similarly, allows the agency to protect against less serious injuries.

b. SID-IIs ATD

i. Background

In the December 2015 RFC notice, NHTSA conveyed its plan to use the SID-IIs ATD currently used in the side MDB NCAP test in the second row left passenger's seat. The agency's plan has not changed in this regard.

In the docket containing this notice, the agency is providing several documents that have been updated for the SID-IIs ATD to reflect the inclusion of: (1) angular rate sensor (ARS) instrumentation in the ATD's head to measure angular head rotation, and (2) redundant accelerometer instrumentation, used currently to measure linear head motion. With the addition of ARS, the agency can measure the angular velocity of the head about its three local axes. This data can then be used to calculate values for BrIC and help the agency better understand the brain injury risks to small occupants in side impact crashes.

Additional documents that support this notice include: (1) a revised PADI,[112] (2) a modified Drawing Package,[113] and (3) updated Technical Specifications.[114] The updated PADI details how to install angular rate sensors in the ATD's head, the drawing package specifies their locations and the related parts lists, and the technical specifications add new qualification requirements for the neck assembly. A separate document detailing R&R results for ARS added

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[111] Ibid.
[112] See "Procedures for Assembly, Disassembly, and Inspection (PADI) for the SID-IIsD Side Impact Crash Test Dummy, New Car Assessment Program, August 2016" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[113] See "Parts List and Drawings, NCAP SID-IIsD Small Female Crash Test Dummy, August 2016" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[114] See "Technical Specifications for the SID-IIsD, Small Adult Female Side Impact Crash Test Dummy, New Car Assessment Program, August 2016" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

to the SID-IIs ATD's head has also been added to the docket.[115] Results of this research are discussed below.

ii. Addition of the Head ARS

In an effort to study the repeatability of the angular velocity of the head of the SID-IIs ATD headform about its three local axes, the head of a SID-IIs ATD was reconfigured to add three angular rate sensors to the current six accelerometer setup (three primary channels and three redundant channels).[116] The agency saw no adverse effect on the mass properties of the head from the instrumentation change; all specification tolerances were maintained. Three head drop tests were also conducted per NCAP's SID-IIs qualification procedure for each of two SID-IIs head configurations – a baseline instrumentation configuration with only CG accelerometers installed, and an ARS with redundant accelerometer instrumentation configuration.[117,118] The CV percent values for the head responses showed excellent repeatability for both instrumentation configurations, and both the maximum resultant and longitudinal accelerations were all within specification. The ARS with redundant accelerometer instrumentation configuration also showed excellent repeatability when compared to the performance of the baseline configuration, indicating that there was no adverse effect from the instrumentation change.

Based on these results, the agency continued with a series of neck qualification tests for the SID-IIs ATD. All tests were conducted in accordance with the neck extension qualification procedures specified in NCAP's SID-IIs qualification procedure; however, an additional

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[115] See "R&R Report for the Neck of the SID-IIsD Side Impact Crash Test Dummy with 3aω Redundant Accelerometer Head" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[116] The x-axis is expected to be the major contributor to BrIC readings in side impact crashes.
[117] See "R&R Report for the Neck of the SID-IIsD Side Impact Crash Test Dummy with 3aω Redundant Accelerometer Head" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[118] This qualification procedure is identical to 49 CFR 572.193 – Neck assembly.

parameter, angular velocity of the headform, was imposed on the neck. The headform that had the ARS with redundant accelerometer instrumentation configuration was used for this assessment. Three SID-IIs ATD necks were tested using the same headform, and five repeat tests were performed for each neck in each qualification test mode (left and right lateral).

Responses for the neck in left and right lateral neck qualification tests exhibited excellent repeatability and reproducibility for the dummies studied and met the existing specifications.[119] The reproducibility data set was also used to calculate a specification requirement for a qualification corridor for neck lateral head angular rate for NCAP's SID-IIs ATDs.

iii. Seating Procedure

A seating procedure outlining the positioning of the SID-IIs dummy in the rear seat of future side NCAP tests was included in the docket for the December 2015 RFC notice.[120] This procedure, which has not been altered since the publication of the December 2015 RFC notice, is essentially the same as the seating procedure used currently to position the rear SID-IIs ATD in side NCAP MDB tests with small modifications. The agency continues to request comment on the changes that have been made.

iv. Validation Testing

As was mentioned previously, the agency conducted six full-scale vehicle crash tests in accordance with the planned side MDB protocol to guide the development of the new 5-Star Safety Ratings system. The SID-IIs ATD was positioned in the rear seat of the vehicles, on the

[119] Ibid.

[120] See "NHTSA SID-IIs 5th Percentile Female Seating Procedure, Rear Seating Position" in NHTSA-2015-0119-0012, available at https://www.regulations.gov/document?D=NHTSA-2015-0119-0012.

struck side, during these six side barrier tests. A table of results can be found in appendix X as well as in the validation testing report docketed with this notice.[121]

In general, BrIC values for the SID-IIs were comparable to those seen for the WorldSID-50M. This is expected since, in a side crash test, the ATD's head, regardless of size, translates very little as it comes into contact with the side curtain air bag. As such, the ATD's head experiences primarily translational, as opposed to rotational, motion. In one instance, the ATD's BrIC value was high; this was likely due to the geometry of the air bag and shape of the chamber, which may have caused excessive head rotation.

This validation testing reaffirmed the feasibility of using the SID-IIs ATD in NCAP testing with ARS.

v. Injury Criteria and Risk Curves

In the December 2015 RFC notice, the agency announced its intent to incorporate HIC_{36}, BrIC, thoracic and abdominal rib deflection, lower spine resultant acceleration, and combined pelvic force injury criteria for the SID-IIs rear passenger dummy in side MDB tests in this NCAP upgrade. Two of these criteria, HIC_{36} and combined pelvic force, are used in the current side NCAP rating system. Other criteria, specifically thoracic and abdominal rib deflections, are measured, but are not part of the current rating system; they are only monitored at this time. Lower spine resultant acceleration readings are also collected currently, and are not used for ratings purposes. However, values in excess of 82 g, the corresponding limit in FMVSS No. 214, are designated as a Safety Concern on www.safercar.gov. The agency still plans to incorporate the majority of these criteria for the SID-IIs ATD tested under the new program. However, some criteria have been modified as a result of new research findings. All updates are summarized in

[121] See "Side Impact Crash Tests Using the WorldSID and SID-IIs Anthropomorphic Test Devices (ATDs)" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

the sections below, and risk curves for all criteria now planned for the SID-IIs dummy are included in appendix V of this notice.

Whereas NCAP currently uses formulae (risk functions) to calculate injury probabilities for each body region measured during testing, the agency is considering the use of SID-IIs risk curves to set lower and upper performance limits for each injury criterion planned for this NCAP upgrade. As stated previously, these lower and upper limits are used to set the boundaries for the linear scale, points-based rating calculation, which is used to determine the crashworthiness ratings. Further details on how the agency will use the injury criteria, risk functions, and performance limits are presented in the ratings system section later in this document.

At this time, the agency is requesting comment on the following criteria:

HEAD – The agency stated in the December 2015 RFC notice that it intended to adopt two head injury criteria for the SID-IIs ATD – HIC to address head injuries induced by translational head acceleration, and BrIC to address brain injuries stemming from rotational motion of the head. Originally, HIC was to be assessed for a 36-millisecond duration (HIC_{36}), and BrIC was to be evaluated at the AIS 3+ severity level. The agency now plans to adopt HIC of a 15-millisecond duration (HIC_{15}) and AIS 4+ BrIC for the SID-IIs ATD for reasons mentioned previously in the WorldSID-50M injury criteria section. Both injury risk curves are included in appendix V of this notice. Details surrounding the development of the new BrIC risk curve can be found in the "Injury Criteria for the THOR 50th Male ATD" report included in the docket for this notice.[122]

CHEST – In the December 2015 RFC notice, the agency included both AIS 3+ and 4+ injury risk curves for thoracic rib deflection for the SID-IIs ATD and sought comment on which

[122] "Injury Criteria for the THOR 50th Male ATD," in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

injury severity level was appropriate to use. Although the SID-IIs, like the ES-2re, is equipped with linear potentiometers, which may not capture the full extent of thoracic (and abdominal) rib deflection in oblique loading conditions, the agency believes that adopting an injury criterion for thoracic rib deflection as part of this program upgrade should not be delayed.[123] The agency believes that instances of high single-point thoracic rib deflection should be included in the new program to better assess potentially injurious loading conditions experienced during the crash test.

At this time, the agency plans to consider an AIS 3+ risk curve to set lower and upper thoracic rib deflection performance limits for the SID-IIs ATD, which aligns with its plan for the WorldSID-50M ATD. The agency believes that selecting an AIS 3+ risk curve should address thoracic injuries that occur more frequently while still mitigating those that are more severe. Importantly also for NCAP, the AIS 3+ injury risk function permits the maximum differentiation of the current NCAP fleet data. For MY 2014-2016 side MDB NCAP tests, thoracic deflection readings (as determined by the maximum deflection of any of the individual thoracic ribs) ranged from a minimum of 0 mm to a maximum of 45 mm. For the AIS 3+ risk curve, these values correspond to 0 percent and 75 percent risk, respectively. The agency notes that currently, deflections in excess of 38 mm (~50 percent risk) only receive a footnote adjacent to their NCAP star rating on www.safercar.gov. Given this data, the agency believes it would be reasonable to establish upper and lower bounds for this injury criterion in the rating system.

Another possible approach could be to set only an upper performance limit for the thoracic rib criterion. In order to set this upper performance limit, NHTSA could review recent

[123] Jensen, J., Berliner, J., Bunn, B., Pietsch, H., Handman, D., Salloum, M., Charlebois, D., & Tylko, S., "Evaluation of an Alternative Thorax Deflection Device in the SID-IIs ATD," The 21st International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 09-0437, 2009, available at http://www-nrd.nhtsa.dot.gov/pdf/esv/esv21/09-0437.pdf.

model year SID-IIs thoracic rib data and base the value upon a certain percentage of the maximum value recorded. NHTSA is seeking comment on such an approach.

a. NHTSA Derived Thoracic Rib Deflection Injury Risk Curve

The agency also requested comment in the December 2015 RFC notice on whether 56-years-old was an appropriate age to base the risk curve for thoracic rib deflection. As noted at that time, this curve has been adjusted to take into account lowered bone mineral density for a 56-year-old female, and the average age of an AIS 3+ injured occupant 5 feet 4 inches or less in stature in side crashes was found to be 56 years.[124] The agency stated that the use of the 56-year-old risk curve for thoracic deflection is appropriate as it should continue to drive safety improvements for the more vulnerable population of occupants that the SID-IIs is meant to represent. The AIS 3+ risk curve for SID-IIs ATD thoracic deflection, included previously in the December 2015 RFC notice, can be found in appendix V. The risk of thoracic injury would be determined by the maximum deflection of any of the individual thoracic ribs.

b. Alternative Thoracic Rib Deflection Injury Risk Curve

The agency is also now requesting comment on an alternative AIS 3+ risk curve that was published in the Stapp Car Crash Journal Volume 60.[125] Irwin et al. stated that the AIS 3+ risk curve included for thoracic rib deflection in the December 2015 RFC notice is inappropriate to use because it was developed from tests with the SID-IIs with floating rib guides (SID-IIs FRG) as opposed to the dummy currently used in NCAP's side program and FMVSS No. 214, the SID-IIs Build Level D. Irwin et al. examined tests conducted by the agency at the Medical College of Wisconsin (MCW) with the SID-IIs D and PMHS in the same test configurations to generate a

[124] Kuppa, S. "Injury Criteria for Side Impact Dummies," National Highway Traffic Safety Administration, January 2006, in NHTSA-2015-0119, available at https://www.regulations.gov/document?D=NHTSA-2015-0119-0011.
[125] Irwin, A., Crawford, G., Gorman, D., Wang, S., Mertz, H., "Thoracic Injury Risk Curves for Rib Deflections of the SID-IIs Build Level D," Stapp Car Crash Journal, 60: 545-580, 2016.

new thoracic rib deflection injury risk curve for the SID-IIs D. For ease of reference, this curve has also been included in appendix V of this notice. The agency notes that the lowest rib deflection in the PMHS experimental data to correspond to AIS ≥ 3 injury for the SID-IIs D was 29.7 mm, and the highest rib deflection to correspond to AIS < 3 injury was 65.5 mm. Furthermore, the overwhelming majority of rib deflections used to generate this risk curve exceeded 40 mm. Yet, only 34 percent of MY 2014-2016 vehicles recorded thoracic rib deflections greater than 30 mm in NCAP's side MDB test, and only 8 percent recorded deflections greater than the current monitored limit of 38 mm. Thirty millimeters corresponds to 4 percent risk of AIS 3+ injury using this alternative curve, and 38 mm corresponds to 21 percent risk. Therefore, the agency is concerned that the use of this risk curve may not provide adequate fleet differentiation. Thus, the agency requests comments on what upper and lower bounds would be reasonable for this injury criterion in the rating system if this risk curve were to be adopted.

ABDOMEN – In its December 2015 RFC notice, the agency requested comment on inclusion of an AIS 4+ injury risk curve, presented for a 56-year-old, for abdominal rib deflection. The agency's plan to adopt this criterion remains the same at this time. Similar to the thoracic rib deflection criterion, the agency believes that adoption of an abdominal rib deflection criterion should be included in the new program. For SID-IIs abdominal rib deflection, the agency is considering establishing only an upper performance limit because the curve planned for adoption has a higher severity level than all of the other injury risk curves for this dummy (with the exception of BrIC). This approach is similar to that previously discussed to address abdomen soft tissues for the WorldSID-50M ATD. As will be outlined in the ratings system section of this notice, the SID-IIs abdominal deflection threshold will be set at 80 percent of the

45 mm limit currently monitored by NCAP. The points assigned to risk of abdominal injury would be determined by the maximum deflection of any of the individual abdominal ribs.

The agency is also considering an alternative method to defining the upper performance limit for abdominal rib deflection. Similar to the SID-IIs thoracic rib deflection criterion, the agency would review recent model year NCAP SID-IIs data and set the upper performance limit at a certain percentage of the maximum abdominal rib deflection observed. NHTSA requests comments on this method.

LOWER SPINE – In the December 2015 RFC notice, the agency sought comment on an appropriate performance criterion limit for resultant lower spine acceleration that could be adopted for the SID-IIs ATD. The agency considered incorporating a performance limit for lower spine acceleration in lieu of a risk curve because, as was the case when NCAP was upgraded in MY 2011, a validated risk curve for the SID-IIs ATD was not available at the time. Since the agency is still not aware of the existence of a valid risk curve for this criterion, the agency plans to proceed with incorporating a performance limit for this criterion, which, similar to that mentioned previously for the abdomen criterion, will be set at 80 percent of the 82g limit currently assessed by NCAP and FVMSS No. 214.[126]

The reason that the agency plans to adopt this criterion for the SID-IIs ATD and not for the WorldSID-50M ATD is because the SID-IIs ATD will only be equipped with linear potentiometers, not the RibEye™ system, like the WorldSID-50M. Whereas the agency reasoned that the RibEye™ system should capture oblique loading, based on the side pole test driver data presented previously, this is not likely to be the case for the SID-IIs since its potentiometers

[126] Details surrounding this limit are provided in the Ratings section of this notice.

measure deflection at a single location.[127] Given this, the agency believes that there is merit in adopting a resultant lower spine acceleration injury criterion for this ATD. The tri-axial lower spine accelerometers are known to provide a good measure of the overall loading on the thorax, and may therefore capture more severe lower thorax and abdomen loading that may otherwise go undetected.

<u>PELVIS</u> – The agency indicated in the December 2015 RFC notice that it would continue to use the AIS 2+ injury criterion for maximum combined (acetabular and iliac) pelvic force that is used currently for the SID-IIs in NCAP's side program. As this injury criterion is also included in FMVSS No. 214 for the SID-IIs dummy, and side MDB testing has shown high combined pelvic force readings for some vehicles in the more recent model year fleet, the agency supports inclusion of this criterion in the upgraded program.[128]

C. Crashworthiness Pedestrian Protection

The December 2015 RFC notice announced the agency's plan for a vehicle crashworthiness assessment for pedestrian safety. FARS data on pedestrian collisions shows there were 4,884 pedestrian fatalities in 2014.

The December 2015 RFC notice explained that the test procedures and rating scheme would be similar to those used by Euro NCAP. These methods make use of three types of component tests to assess how well a vehicle, traveling at 40 km/h, can mitigate injuries to a struck pedestrian. The procedures are adaptable to a wide range of vehicle sizes and shapes. They are also applicable to pedestrians of different stature, and to adults and children alike. The

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[127] The SID-IIs may also be fitted with the RibEye™ instrumentation. However, due to cost and the ongoing development of the WorldSID-5th percentile female, NHTSA has decided against pursuing this option. Despite this, comments are requested on the merits of outfitting the SID-IIs ATD with the RibEye™ system.
[128] Five vehicles reported an elevated combined pelvic force for the rear passenger in MDB tests for MY 2014-2016 NCAP testing. Two of the five exceeded the IARV of 5,525 N.

assessment captures the injurious interactions between pedestrians and vehicles during a collision of the lower leg with the bumper, the femur and pelvis with the upper front-end, and the head with the hood, lower windshield, and A-pillar.

1. Assessment Methods: Multiple Component Tests

The pedestrian crashworthiness program consists of multiple tests, with each test mimicking the interaction of a pedestrian's body region (the head, upper leg, or lower leg) with a particular point of impact on the surface of the vehicle.[129]

2. Changes from Euro NCAP Test Protocol

NHTSA plans on using the Euro NCAP testing protocol on all vehicles, including pickup trucks and large SUVs. The agency does not plan to use a separate heavy vehicle protocol, which was the practice of Euro NCAP in previous years. For the most part, the procedures of Euro NCAP Testing Protocol V8.2 are applicable to all vehicles selected for testing under the NCAP upgrade. This includes headform testing on grid points forward of the hood (or bonnet) leading edge (BLE), where the procedure stipulates an impact angle of 20 degrees. However, some slight adjustments to the Euro NCAP testing protocol, which were not discussed in the December 2015 notice, are needed to accommodate full size pickups and improve test practices. They are discussed below.

Use of Flex-PLI on pickup trucks. The Flex-PLI would be used in testing of all vehicles under the program upgrade, including pickups or vans where the lower bumper reference line (LBRL) is greater than 425 mm. When the lower bumper reference line exceeds 425 mm, Euro NCAP gives manufacturers the option of testing with the upper legform in lieu of the Flex-PLI. The agency plans to always use the Flex-PLI even if the LBRL exceeds 425 mm. Otherwise, it

[129] The drawing packages, Procedures for Assembly, Disassembly, and Inspection (PADIs), and technical evaluation reports for each of the pedestrian test devices are located in the Docket No. NHTSA-2015-0119.

could lead to a situation where a high-bumper vehicle, such as a pickup truck, receives a very good rating for lower leg safety, when in fact the vehicle does a very poor job of mitigating lower leg injuries in the real world. NHTSA believes this would be misleading to consumers and possibly frustrate the goals of NCAP.

Providing manufacturers with the option of using the upper legform, as opposed to the Flex-PLI, provides a means to assure some level of minimum performance, which makes it acceptable for PASS/FAIL purposes in regulations such as the United Nations Economic Commission for Europe (UNECE) Regulation No. 127 "Uniform provisions concerning the approval of motor vehicles with regard to their pedestrian safety performance." However, since an NCAP star rating is meant to aid consumers in comparing the safety of one vehicle vs. another, allowing the option to use different test devices could generate conflicting or misleading ratings since the test parameters and test devices used to generate the ratings are not the same.

No bumper testing when LBRL>500 mm. When the LBRL exceeds 500 mm, the agency does not plan to carry out a bumper assessment. Instead, the agency plans to simply assign a "default red, no points" score to the particular grid point under assessment. The agency notes that Euro NCAP testing protocol stipulates that the upper legform must be used when LBRL exceeds 500 mm, and there is no option to use the Flex PLI. Similar to NHTSA's rationale on when the LBRL exceeds 425 mm, NHTSA believes that using the upper legform in lieu of the Flex PLI could result in an inaccurate or misleading bumper rating. Also, the situation would result in a test redundancy because the "WAD775"[130] upper legform test and the "in lieu

[130] The term "Wrap Around Distance (WAD)" is a distance measurement made using a flexible tape measure. One end of the tape is held at ground level directly below the bumper. The other end is wrapped around the front end of a vehicle and held taut and in contact with a point on the hood or windshield. WAD775 refers to a point on the hood with a wrap around distance of 775 mm.

of the Flex PLI" upper legform test would be carried out on target points that are very close together.

Assessing the bumper with the Flex-PLI (when the LBRL is greater than 500 mm) is not an appropriate use of the device. Such a test condition is beyond the limits for which the Flex-PLI serves as a useful tool, which is also why it is not used in UNECE Regulation No. 127 when LBRL exceeds 500 mm. If a Flex-PLI test is conducted on such a bumper, the legform's lack of an upper body structure could result in a condition where, upon impact, it is redirected groundward with very little tibia bending and knee displacement, thus leading to an artificially good test score. Such action does not represent a human-to-vehicle interaction, and high-bumper front-ends have been shown to be highly injurious to pedestrians. In the real world, bumpers that strike above the knee level cause the upper body and lower leg to rotate in opposite directions resulting in severe knee trauma.[131] Therefore, vehicles with LBRL 500 mm or higher would be given "default red, no points" for the bumper assessment. NHTSA would still conduct the WAD775 assessment with the upper legform.

Using upper legform worst case scenario when artificial interference is present. When testing a high-bumper vehicle, the WAD775 mark may appear on the grille of the vehicle, well below the bonnet leading edge. In this instance, the upper legform is directed horizontally into the front face of the vehicle front-end with contact points all along impactor, from top to bottom. If the front-end is not completely flush, it could lead to a condition in which either the top or bottom edge of the impactor could just "catch" a protruding vehicle component, such as the top edge of the bumper. When this occurs, the impactor could glance off the component in

[131] Simms C and Wood D (2009), "Pedestrian and cyclist impact: a biomechanical perspective," Springer, IBSN 978-90-481-2742-9, Dordrecht, London, Heidelberg, New York, 2009.

such a way as to absorb a significant amount of impactor energy without registering a significant moment or force in the instrument.

This situation is an artifact of the component test and does not represent real-world vehicle-to-pedestrian interaction. The agency encountered this situation when it tested the Ford F-150. If this situation occurs during a test, NHTSA would remove the effect by re-positioning the legform and moving it up or down the WAD line to a "worst case" position that is no greater than +/- 50 mm from the WAD775 target.

Revised bumper corner definition. In the Euro NCAP test protocol, the width of the Flex-PLI test area is defined by the point of contact of a 60 degree plane and the forward-most point on the vehicle front-end. Up until 2016, the same definition was used in European pedestrian regulations that resulted in a vehicle design trend in which protruding "touch points" are molded into the lower portion of the fascia. The touch points may be placed strategically to contact the 60 degree plane as a means for vehicle manufacturers to control the width of the test area. In some models, the touch points reduce the test area to as little as 40 percent of the vehicle width.[132]

An analysis of pedestrian casualty data from the United Kingdom (U.K.) and Germany showed that vehicle-pedestrian contacts were distributed across the width of the vehicle, and pedestrians who were struck by a vehicle could receive leg injuries from all regions of the vehicle front. It was not obvious that any one region was particularly safe or injurious. NHTSA believes that the same situation exists in the U.S.

In 2016, UNECE Regulation No. 127 was amended with a new procedure that diminishes the width-reducing effects of fascia touch points. The new procedure also includes a stipulation

[132] Transportation Research Laboratory CPR1825

to assure that the entire width of the bumper beam (the very stiff structure underlying the fascia) is included in the test area. This stipulation also appears in the current Euro NCAP test protocol,[133] and NHTSA tentatively plans to use the new procedure for this NCAP upgrade.

<u>Flex-PLI qualification</u>. In UNECE Regulation No. 127, the specifications for the Flex-PLI qualification requirements involve either a pendulum test or an inverse impact test. In Euro NCAP, only the inverse impact test is specified. For this program upgrade, NHTSA currently plans to specify only the pendulum test. NHTSA found the pendulum procedure easier to administer while vehicle testing is in progress and is satisfied that this qualification test assures the legform is performing correctly before resuming vehicle tests.[134]

<u>Other adjustments to the Euro NCAP test protocol</u>. For active hoods, the agency would require that manufacturers demonstrate that their system activates when there is a leg-to-bumper impact that is no further inboard than the point coinciding in the Y-plane with the widest point on the deployable hood. This is not clearly specified in the Euro NCAP procedure. The agency believes that this requirement would ensure that a head-to-hood impact subsequent to the initial bumper-to-pedestrian impact would occur on a hood that has been activated for a safe impact.

3. Validation Testing

The agency completed a full series of headform, upper leg, and lower leg tests on six vehicles representing the U.S. fleet: 2015 Ford F-150, 2016 Chevrolet Malibu Limited, 2016 Honda Fit, 2015 Toyota Sienna, 2016 Nissan Rogue, and 2016 Chevrolet Tahoe. The data

[133] Euro NCAP Pedestrian Testing Protocol, Version 8.2. November 2015. See http://euroncap.blob.core.windows.net/media/21384/euro-ncap-pedestrian-testing-protocol-v82-november-2015.pdf

[134] See “Technical Evaluation of the Flexible Pedestrian Legform Impactor (Flex-PLI)” in Docket No. NHTSA-2015-0119.

generated from this testing is found in appendix XII. More details on the tests are found in the vehicle test reports, which are included in the docket for this notice.

In these tests, the Euro NCAP testing protocol was followed verbatim, with the exception of test point selection.[135] Since NHTSA did not have manufacturer input on the test points, the agency could not apply the Excel worksheet prepared by Euro NCAP to select verification points. Also, the agency did not want to use the previous version of the test protocol, V5.3, which is applied by Euro NCAP when manufacturer input is absent. The V5.3 protocol involves the selection of "worst-case" points that may have led to a lower score than is the norm for Euro NCAP. Instead, NHTSA selected test points by selecting "representative" points based on European variants of two of the agency's pilot vehicles that were also tested by Euro NCAP. This way, the results could be averaged such that the headform score would be comparable to what would have resulted if the agency had manufacturer input and used the Excel worksheet.[136] Essentially, for headform impacts, NHTSA attempted to evaluate an equal number of good, poor, and medium severity locations based on previous experience testing vehicle hoods. For the upper and lower leg tests, the agency tested at the vehicle centerline, edge, and at one or two areas between the center and edge of the Euro NCAP prescribed bumper test area. Results from this testing series are discussed in the "Pedestrian Crashworthiness Rating" section of this notice.

[135] See "Technical Modifications to: Euro NCAP Pedestrian Testing Protocol, Version 8.2 for use in the New Car Assessment Program" in Docket No. NHTSA-2015-0119.

[136] European variants of two of the agency's pilot vehicles were also tested by Euro NCAP: the Nissan Rogue (X-Trail) and the Honda Fit (Jazz). The agency applied its test results to the full Euro NCAP scoresheet populated with manufacturer input for the X-Trail and Jazz and computed the scores. In comparison to scores computed via the agency's "representative" process, the scoresheet yielded essentially the same scores: 3% lower for the Nissan Rogue and 6% lower for the Honda Fit.

4. Injury Criteria and Risk Curves

The selection of performance limits for the measurements of the pedestrian test devices was guided in part by their established correlations with human injury risk, which are described in detail in the report titled, "Pedestrian Injury Risk Functions for the New Car Assessment Program," included in the docket of this notice. The injury risk functions themselves are listed in appendix VI for each device. Details on how the devices and performance limits are used to assess pedestrian crashworthiness are found in the "Pedestrian Protection Rating" section of this notice.

D. Crash Avoidance Pedestrian Protection

In the December 2015 RFC notice,[137] the agency identified two crash avoidance systems that detect pedestrians and automatically apply braking force, if necessary, to avoid a crash. The first system, Pedestrian Automatic Emergency Breaking (PAEB), is an advanced driver assistance technology that would provide automatic braking for vehicles when pedestrians are in the forward path of travel and the driver is taking insufficient action to avoid an imminent collision. The second system, rear automatic braking, is defined by NHTSA as a system that would automatically apply a vehicle's brakes, independent of a driver's action, in response to the presence of a pedestrian or an object in a specified area behind the vehicle during backing.[138] With this notice, the agency is publishing a draft test procedure for evaluation of PAEB

[137] 80 FR 78522.

[138] In December 2015, the NCAP Rear Automatic Braking Feature Confirmation test procedure was uploaded into Docket No. NHTSA-2015-0119-0030 (*see* https://www.regulations.gov/document?D=NHTSA-2015-0119-0030) as part of the December 16, 2015, NCAP RFC notice.

systems.[139] NCAP test procedures for all 11 proposed crash avoidance systems, including these two pedestrian-related systems, are available in Docket No. NHTSA-2015-0119.

One important aspect of the PAEB test procedure is the speed at which the test should be run to best represent actual pedestrian crashes. The posted speed limit recorded in traffic accident reports and crash datasets provides the most reasonable means of estimating vehicle speed at impact in pedestrian crash analysis. The 1994-1998 Pedestrian Crash Data Study (PCDS)[140] data was used to guide early PAEB research and decision-making with respect to the proposed test scenarios. The PCDS shows the types of impacts that occur with pedestrians, which is helpful. Even so, it is a relatively narrow study. Since PCDS is not a pure statistical sample but rather a study of pedestrians with incapacitating or fatal injuries, and the data is now over 20 years old, more recent and broader studies were considered for evaluating pedestrian crash avoidance test parameters, such as speed limits and crash characteristics.

Multiple data sources show that crashes involving pedestrians at posted speed limits less than 30 mph most often result in injuries, and crashes involving pedestrians at posted speed limits greater than 40 mph most often result in fatalities. Jermakian and Zuby[141] analyzed data from the General Estimates System (GES) and FARS databases spanning the years 2005 to 2009 and reported that although 72 percent of pedestrian impact crashes occurred with a posted speed limit less than 40 mph, it accounts for 37 percent of pedestrian fatalities. Time of day showed a similar dynamic, as 59 percent of pedestrian impact crashes occurred during daylight, while 28

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139 Draft "Test Procedure for Evaluation of Pedestrian Automatic Emergency Brake Systems on Light Vehicles For NCAP" is located in Docket No. NHTSA-2015-0119 (https://www.regulations.gov/docket?D=NHTSA-2015-0119).
140 PCDS is a 550 crash case study that collected data from 6 U.S. cities spanning the years 1994-1998. The purpose of the NHTSA special study was to investigate the differences between pedestrian collisions involving passenger cars and light trucks (utility, vans, and pick-ups), and to reconstruct two PCDS cases (one car, one truck) in sled tests with a pedestrian dummy for experimental testing.
141 Jermakian, J. S. and Zuby, D. S., "Primary Pedestrian Crash Scenarios: Factors Relevant to the Design of Pedestrian Detection Systems, Insurance Institute for Highway Safety," April 2011. Available at http://www.iihs.org/frontend/iihs/documents/masterfiledocs.ashx?id=1888.

percent of pedestrian fatalities occurred during dark conditions. A NHTSA study[142] examined pedestrian crash deaths by posted speed limit over the period 1997 to 2006. The findings indicate that the largest proportion (32 percent) of pedestrian fatalities occurred on roads with posted speed limits of 50 miles per hour or higher compared to all other posted speed limits, followed by roads with posted speed limits of 30 to 39 miles per hour (29 percent). By comparison, FARS data indicates that approximately 60 percent of all vehicle occupant fatalities occurred on roads with posted speed limits of 50 miles per hour or higher, followed by roads with posted speed limits of 40 to 49 miles per hour (21 percent) and posted speed limits of 30 to 39 miles per hour (14 percent). Similarly, Jermakian and Zuby found that 28 percent of pedestrian fatalities occurred on roads with posted speed limits of 50 miles per hour or higher, 30 percent for posted speed limits between 40 and 49 mph, 28 percent for posted speed limits between 30 and 39 mph, and 8.5 percent for posted speed limits below 30 mph. Furthermore, the Jermakian and Zuby analysis suggests PAEB systems could prevent or mitigate as many as 3,279 fatal crashes and 37,000 injury crashes each year. Preliminary NHTSA testing shows that some systems currently available on production vehicles avoid a crash with a pedestrian at vehicle speeds up to 35 mph.

Figure 1 shows the inverse relationship between pedestrians that are impacted at low speeds (higher risk for injuries) and pedestrians that are impacted at higher speeds (higher risk for fatalities). A normalized plot allows values from different scales to be presented on a common scale. The normalized pedestrian impact ratios plotted by posted speed limit shows that the planned NCAP PAEB test scenarios with impacts at low speeds (i.e, 10 mph and 25 mph) currently address pedestrian safety improvement potential for reducing injuries and a small number of lower speed fatalities. As PAEB systems evolve to perform well at higher speeds, the

[142] DOT HS 810 968, "National Pedestrian Crash Report." NHTSA. June 2008. Available at https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/810968.

agency expects to realize safety improvement at reducing fatalities. The plot of FARS and GES data aids the industry to center the focus on advancing and improving PAEB performance over the speed range 30-45 mph (48-72 km/h). Systems that perform well at the middle and higher speed ranges will begin to shift the safety improvement potential from primarily injuries towards a more even split of injuries and fatalities. Additionally, FARS data indicates a considerable difference in crash outcomes sorted by lighting conditions, and that at any speed above 25 mph (40 km/h), more fatalities occur in dark conditions rather than daylight.

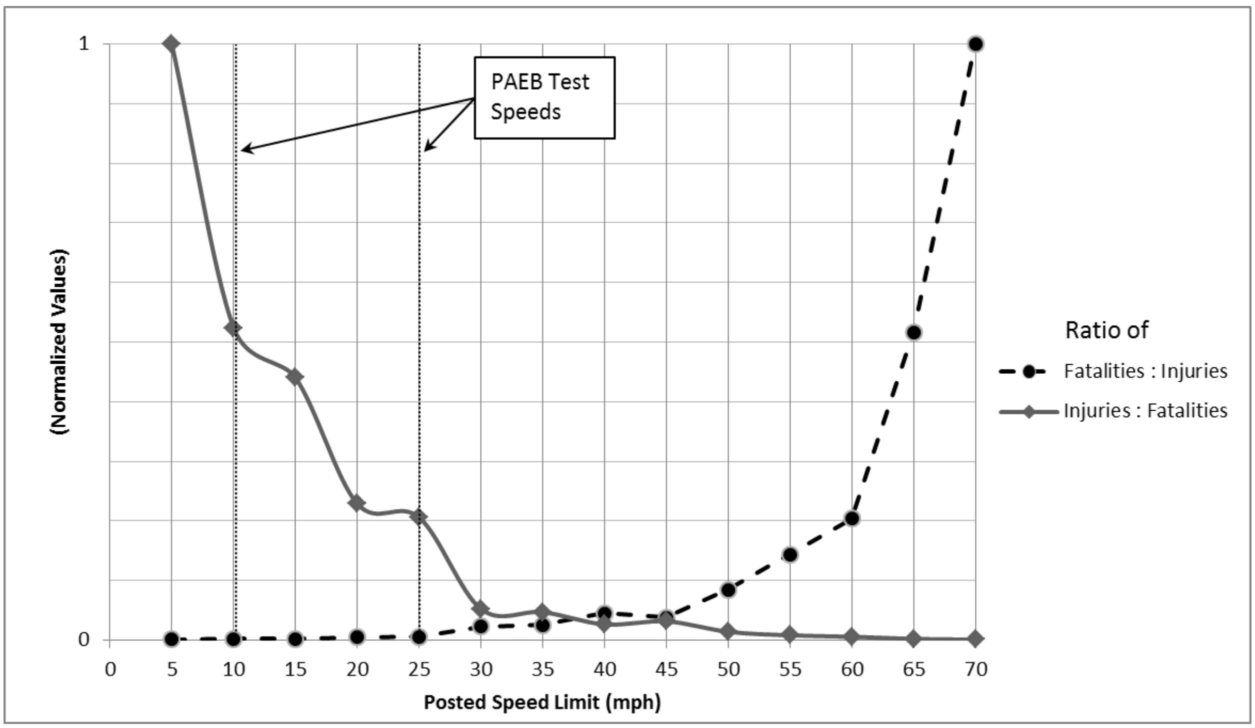

Figure 1 – FARS and GES Pedestrian Impacts by Posted Speed Limit

The pedestrian injury and fatality statistics were examined to give proper context to the test scenarios selected for the PAEB test series. A more recent NHTSA analysis[143] of GES and

[143] Yanagisawa, M., Swanson, E., & Najm, W. G. (2014, April). "Target Crashes and Safety Benefits Estimation Methodology for Pedestrian Crash Avoidance/Mitigation Systems." (Report No. DOT HS 811 998). Washington, DC: National Highway Traffic Safety Administration, available at

FARS crash databases shows that the highest frequencies of pedestrian crashes occur at speeds of 30 mph (48 km/h) or less, at intersections, on non-divided roads, in clear and dry weather, on dry roads, during daylight, and without driver alcohol involvement. Less severe injuries were associated with lower impact speeds, typically at intersections and/or involving vehicle-turning scenarios. The majority of crashes involving fatalities occurred at higher impact speeds, involved pedestrians on the roadway outside of the crosswalk, occurred at non-junctions, were associated with darkness, had pedestrian alcohol involvement, and involved pedestrians older than 29 years of age.

Examination of 2014 pedestrian crash data collected by NHTSA[144] shows pedestrian fatalities in traffic crashes are primarily attributed to the following: urban areas (78 percent), initial point of impact at the front of the vehicle (75 percent), dark lighting conditions (72 percent), non-intersections (71 percent), and male gender (70 percent). Light truck involvement (42.6 percent) is similar to passenger car involvement (41.4 percent) for single-vehicle crashes.

Cameras in PAEB systems work in reduced lighting conditions, and low beam headlighting systems aid camera PAEB system performance during dark lighting conditions. With more pedestrian fatality crashes occurring during dark conditions, a strong interdependency between lighting and PAEB performance exists. SAE technical report J2829 suggests that pedestrians approaching perpendicular to the Subject Vehicle (SV) from the left in dark lighting conditions are more vulnerable than pedestrians approaching from the right by a ratio of 2:1.[145]

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http://www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2014/811998-TargCrashSafBenEstMethPedCrashAvMitSys.pdf.

[144] National Center for Statistics and Analysis. (2016, May). "Pedestrians: 2014 data." (Traffic Safety Facts. Report No. DOT HS 812 270). Washington, DC: National Highway Traffic Safety Administration, available at https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812270.

[145] SAE J2829 FEB2011, "Pedestrian Visibility – Low Beam Optimization to Reduce Night-time Fatalities," available at http://standards.sae.org/j2829_201102/.

Separately, a Federal Highway Administration (FHWA) study[146] of vehicle and pedestrian crashes found that although vehicle turning movements averaged only 14 percent of the total intersection volume, turning crashes approached 45 percent of the total. Left-turn crashes exceeded right-turn crashes by a ratio of 2:1. This is in contrast to the PCDS data, which showed an even distribution of pedestrians walking from left-to-right in front of a vehicle as compared to right-to-left. PCDS counted 167 pedestrian impacts left-to-right and 173 pedestrian impacts right-to-left. For pedestrians walking along the roadway, all PCDS cases involved a pedestrian walking with the traffic.

The proposed PAEB tests focus on two of the scenarios defined by the Crash Avoidance Metrics Partnership (CAMP) Crash Imminent Braking (CIB) Consortium[147] and identified in the initial request for comments as Scenario 1 (S1) and Scenario 4 (S4), with multiple pedestrian impact locations. In the S1 scenario, the subject vehicle travels in a straight, forward direction and a pedestrian mannequin crosses perpendicular to the vehicle line of travel. In test S1a, the SV encounters a crossing adult pedestrian mannequin walking from the nearside (i.e., the side of the vehicle closest to the curb) with 25 percent overlap. (Overlap is defined as the percent of the vehicle's width that the pedestrian would have traversed prior to impact if the vehicle's speed and pedestrian's speed had remained constant.) In test S1b, the SV encounters a crossing adult pedestrian walking from the nearside with 50 percent overlap. In test S1c, the SV encounters a crossing adult pedestrian walking from the nearside with 75 percent overlap. In test S1d, the SV

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[146] Federal Highway Administration. (2003, November). "A Review of Pedestrian Safety Research in the United States and Abroad." (Final Report No. FHWA-RD-03-042) available at http://www.fhwa.dot.gov/publications/research/safety/pedbike/03042/part3.cfm.

[147] Carpenter, M. G., Moury, M. T., Skvarce, J. R., Struck, M. Zwicky, T. D., & Kiger, S. M. (2014, June). Objective tests for forward looking pedestrian crash avoidance/mitigation systems, Final report. (Report No. DOT HS 812 040). Washington, DC: National Highway Traffic Safety Administration, available at https://one.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2014/812040_camp_flv_mitigationreport.pdf

encounters a crossing child pedestrian running from behind parked vehicles from the nearside with 50 percent overlap. In test S1e, the SV encounters a crossing adult pedestrian running from the “offside” (i.e., the side of the vehicle closest to the center of the road) with 50 percent overlap. In test S1f, the SV encounters a crossing adult pedestrian walking from the nearside that stops short of entering the vehicle’s path. In test S1g, the SV encounters a crossing adult pedestrian walking from the nearside that clears the vehicle’s path.

In the S4 test scenario, the subject vehicle travels in a straight, forward direction and a pedestrian mannequin moves parallel to the flow of traffic in front of the subject vehicle. For all S4 test conditions, the SV will be aligned to impact the pedestrian at 25 percent overlap. In test S4a, the SV encounters an adult pedestrian standing in front of the vehicle on the nearside of the road facing away from the approaching subject vehicle. In test S4b, the SV encounters an adult pedestrian standing in front of the vehicle on the nearside of the road facing towards the approaching subject vehicle. In test S4c, the SV encounters an adult pedestrian walking in front of the vehicle on the nearside of the road facing away from the approaching subject vehicle.

As discussed earlier in this section, key elements of the pedestrian safety problem are addressed by NCAP testing of scenarios S1 and S4. The crash data supports harmonizing the U.S. NCAP’s pedestrian crash avoidance test scenarios S1a, S1c, S1d, and S1e with Euro NCAP test procedure scenarios CVNA-25, CVNA-75, CVNC, and CVFA, respectively. Additionally, the agency will test a crossing adult pedestrian mannequin walking from the nearside at 50 percent of the way across the front of the vehicle (S1b), two false-positive conditions (S1f and S1g), and three conditions with an adult pedestrian positioned on the nearside of the road and oriented parallel to the subject vehicle direction of travel (S4). With respect to S4, a substantial percentage of fatal and injury crashes in the U.S. occur while the pedestrian is moving parallel to the side of the road, using the side of the road as a walkway. This differs from the situation in Europe. Based on German In-Depth Accident Study (GIDAS) data, a very small percentage of German pedestrians were struck while moving along the road in the direction of travel. A much larger percentage of pedestrians are struck in the United States in the S4 scenario. Since this scenario tends to result in more severe pedestrian injuries, the agency has tentatively decided that S4 be included in NCAP.

The agency regards test conditions S1f and S1g as important measures of the safety potential of a PAEB system while also helpful in evaluating and minimizing system activations under a false threat that could lead to a rear-end collision. This would be an example of a false-positive. The agency seeks to characterize the robustness of a PAEB system's algorithm with the S1f and S1g tests. The agency requests comment regarding the pedestrian mannequin locations specified in test conditions S1f and S1g.

The PAEB test procedure also specifies two pedestrian test targets. These targets are strikeable mannequins with characteristics representative of a 50th percentile adult male and a 6- or 7-year-old child, each clothed with a long-sleeved shirt and long pants. The mannequins used in PAEB testing must possess the radar characteristics that would be similar to that of a real pedestrian from any angle.[148] One example of a conforming test device is the non-articulating mannequin produced by 4activeSystems GmbH of Austria, which is the same mannequin used by Euro NCAP for their PAEB test track evaluations.[149] So as to harmonize with Euro NCAP, NHTSA tentatively plans to use the 4a Euro NCAP Male Adult and Child Pedestrian Targets in

[148] Refer to the 4active systems website (http://www.4activesystems.at/en/downloads/manuals.html, accessed on August 24, 2016) for the specific mannequin characteristics in the product brochure.
[149] European New Car Assessment Programme (Euro NCAP), Test Protocol – AEB VRU Systems, Version 1.0.1, June 2015, available at http://euroncap.blob.core.windows.net/media/21509/euro-ncap-aeb-vru-test-protocol-v101.pdf.

the agency's NCAP PAEB tests and the 4a Euro NCAP Child Pedestrian Target in the agency's rear automatic braking tests. However, vehicle manufacturers may use any mannequin with radar characteristics representative of the human pedestrian profile for their self-generated performance test data.

One of the agency's goals is to design reasonable crash avoidance test and evaluation programs. More specifically, the agency desires to test new vehicles equipped with crash avoidance technologies using the minimum number of scenarios and repeated trials that are capable of objectively quantifying whether the system performance is acceptable. Bounded by extreme opposing options of a single compliance test versus testing every new vehicle produced, the agency seeks to characterize the performance of crash avoidance systems on new vehicles with a sufficient number of trials covering a variety of test conditions. Respectful of best practices, NHTSA uses technical standards that are developed or adopted by voluntary consensus standards bodies as a means to carry out agency safety-related policy objectives and activities. By applying a statistical approach to the PAEB test criteria, NHTSA believes that the problem of characterizing system performance based on a limited number of specific test conditions can be solved by using a non-parametric binomial reliability demonstration test methodology with associated confidence levels. In statistical analysis, a binomial process is described by a number of independent identical trials, each one having the same probability of success, which produces a number of successes from those identical trials. For NCAP, the PAEB test series consists of 89 repeated trials that are independent of one another because the outcome of one trial does not affect the outcome of other trials. While the PAEB test conditions physically differ from each other, operationally, NHTSA is only concerned about whether a vehicle achieves success or failure for each trial. In this operational sense, all of the trials can be considered to be identical.

Each trial can result in one of two possible outcomes, a success or a failure, and the probability of success is assumed to be the same on every trial (0.5). (While testing experience has shown that some test conditions are easier for vehicles to succeed in, NHTSA has tentatively decided to ignore these differences.) The draft NCAP PAEB test procedure indicates that a failed trial outcome occurs when the vehicle contacts the mannequin for 11 of the 15 PAEB test conditions. The remaining PAEB test conditions can be categorized in two manners. For scenarios with virtually no reaction time, such as stepping off of a curb at the last moment, a failure occurs if the specified speed reduction is not achieved. For false positive tests, such as a person standing on the side of the road, a failure occurs if the vehicle decelerates more than a specified amount.

As an evolution beyond the five of seven test pass criterion presently used for well-developed technologies like FCW, a reliability/confidence methodology is expected to improve the statistical basis without drastically departing from the current NCAP crash avoidance testing approach. Within the scope of the NCAP PAEB pass criteria, reliability would be defined such that a vehicle will continue to function at expected safety levels for defined metrics and under specified system performance conditions, whereas the confidence level represents how well the test results estimate the true population parameter.

Within NCAP, PAEB performance would be evaluated as an aggregate of all 15 test conditions. Embedded in the aggregate would be a multi-tiered test criterion that not only aligns with an immediate desire by NHTSA to reduce pedestrian impacts, fatalities and injuries, but also allows for incremental future improvement and testing of PAEB system algorithms that expand the pedestrian impact elimination potential beyond primarily injuries to fatalities that occur at higher speeds. The agency recognizes that system performance is not solely a function of camera and/or sensor field of view (FOV); such things as camera resolution, radar sensitivity, and the maturity of the pedestrian detection software are also very important for PAEB performance. Additionally, the agency is aware that current PAEB system FOV settings align with certain vehicle speed ranges and detection distances, which pose a challenge to achieving a passing score for all three tiered combinations. Systems with a narrow FOV (i.e., can see further) have the potential to be more effective at higher speeds, while systems with a wider FOV have the potential to be more effective at lower speeds.

For each tier of the PAEB criterion, NCAP selected a desired level of reliability to be demonstrated and a test confidence level. The terminology is presented in the form "percent reliability/percent confidence." As an example, "85%/90%" is read as 85 percent reliability to be demonstrated with 90 percent confidence. In other words, if the system reliability is less than 85 percent, the chances of passing this test are less than 10 percent (calculated as 100 percent minus the confidence level, which in this example is 90 percent). Additionally, the number of test failures that can occur for each tier of the PAEB criterion is defined. Using a statistical sample size calculator software program, the minimum number of test trials is generated for the given reliability/confidence pairing and the number of test failures allowed.

The draft PAEB test procedure describes the three-stage pass criteria. The first stage (Tier 1) combines scenarios S1a with S1b, S1c, S1d, and S1e for a total of 40 test trials. The agency desires robust system performance in these test conditions because they represent the largest percentage of estimated pedestrian crashes (53 percent)[150] and fatalities (59 percent)[144] that could be prevented by PAEB systems. The pass criterion determined for this tier allows one failure during the 40 test trials, which achieves a reliability/confidence of approximately 90%/90%. The

[150] Blower, D., "Key Pedestrian Collision Scenarios in the U.S. for Effective Collision Avoidance Technologies," Report No. UMTRI-2014-18, May 2014, available at https://deepblue.lib.umich.edu/bitstream/handle/2027.42/108383/103023.pdf?sequence=1.

second PAEB stage (Tier 1 + 2) adds 35 test trials comprised of scenarios S4a, S4b, and S4c (making a total of 75 trials for all Tier 1 + 2 scenarios). Cumulatively through the first and second tiers, the PAEB pass criterion allows no more than four failures in 75 test trials, which corresponds to a reliability/confidence of approximately 90%/90%. The third stage (Tier 1 + 2 + 3) adds both false-positive scenarios S1f and S1g, such that the full test series totals 89 test trials. In recognition that detection system algorithms currently may have problems accurately classifying the S1f and S1g scenarios as false positives, the initial full PAEB test series pass criterion would be set at 8 failures during 89 test trials, which achieves the 85%/90% level. Table 1 lists a summary of the NCAP PAEB pass criteria and the results from the test procedure verification testing conducted by NHTSA.[151]

Table 1 – Results from NHTSA 2016 NCAP PAEB Verification Testing

	Tier 1	**Tier 1 + 2**	**Tier 1 + 2 + 3**
PAEB Test Summary	8 conditions, 5 trials each	40 Tier 1 trials plus 5 conditions, 7 trials each	40 Tier 1 trials and 35 Tier 2 trials plus 2 conditions, 7 trials each
Test Pass Criteria	1 test failure during 40 trials	4 test failures during 75 trials	8 test failures during 89 trials
Vehicle 1	Pass, 0 test failures	Fail, 5 test failures	Fail, 10 test failures
Vehicle 2	Fail, 4 test failures	Pass, 4 test failures	Pass, 5 test failures
Vehicle 3	Pass, 0 test failures	Fail, 6 test failures	Fail, 13 test failures

The multi-staged pass criteria recommended for PAEB strikes a balance between evolving system design and promoting performance capable of reducing real-world harm resulting from vehicle-to-pedestrian and vehicle-to-pedalcyclist[152] crashes. Departing from the criterion used for NCAP AEB performance, which allows two failures in seven trials for each test condition equating to a simple calculated pass rate of 71 percent, the agency seeks a more

[151] Testing conducted by NHTSA's Vehicle Research and Test Center (VRTC) in May - June 2016. Report pending.
[152] The agency is interested in addressing the vehicle-to-pedalcyclist safety problem by including pedalcyclists in the discussion of the real-world pedestrian data. NHTSA is aware of a commercially available pedalcyclist test target, however the PAEB test procedure does not include pedalcyclists at this time.

rigorous criterion when the crash involves pedestrians or pedalcyclists as compared to another vehicle because pedestrians and pedalcyclists are more vulnerable than vehicle occupants due to their being unprotected and the absence of energy absorbing structural components. Tier 1 represents 88 percent of the occurrences of the top 20 pedestrian fatality scenarios, and Tier 2 represents 12 percent of the occurrences of the top 20 pedestrian fatality scenarios.[144] The agency requests comment on the multi-staged pass criteria described in this section, as well as the 90%/90% and 85%/90% levels selected for PAEB performance.

Finally, the agency is considering adjusting the number of brake burnish stops specified in the PAEB test procedure (200 stops) to a lower number of stops. The agency has reconsidered the data from a seven vehicle IIHS test series published in an SAE technical paper.[153] In this IIHS study, six of the seven vehicles tested achieved maximum AEB speed reductions after 60 or fewer stops. Additionally, the agency is aware that the Euro NCAP AEB Pedestrian test procedure specifies only 23 stops.[148] NHTSA requests comment on whether the industry believes brake burnishing of this magnitude (200 stops) is necessary for the NCAP PAEB tests.

Brake burnishing conditions the brake system hardware so as to achieve its full capability. NHTSA established the 200-stop brake burnishing procedure in a 1987 notice.[154] NHTSA testing[155] conducted during the development of FMVSS No. 135, "Light vehicle brake systems," showed that, in some cases, stopping distances were somewhat shorter after burnish, and in other cases, stopping distances were shorter in the unburnished state. The overall conclusion was that the burnish had a small effect on stopping distances. Since most

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[153] Wilson, M., Aylor, D., Zuby, D., and Nolan, J., "Brake Burnishing Effect on AEB Performance," SAE Int. J. Trans. Safety 3(1):39-46, 2015, doi:10.4271/2015-01-1481, also available at https://www.regulations.gov/document?D=NHTSA-2015-0006-0012, starting on page 38.

[154] 52 FR 1474, published in the Federal Register on January 14, 1987.

[155] Harmonization of Braking Regulations—Report No. 1, "Evaluation of First Proposed Test Procedure for Passenger Cars, Volume 1," May, 1983, DOT HS 806 452.

manufacturers switched from drum to disc brakes during the early 1970s,[156] new cars have disc brakes on the front wheels and either disc or drum brakes on the rear wheels. Additionally, most owner's manuals caution that newly purchased passenger cars do not need an elaborate 'break-in' process, and that vehicle brakes will perform better if drivers avoid making hard stops during the initial 200 miles (322 km) of driving.

Following brake replacement service, manufacturers of replacement brake equipment such as Bendix,[157] Federal-Mogul,[158] Wagner,[159] and National Automotive Parts Association (NAPA)[160]recommend performing 30 stops, 20 stops, 20 stops, and 15 stops respectively, with a 30-mph (48 km/h) speed reduction and a 30-second cooling interval between stops. Replacement brake equipment guidelines indicate the 15 – 30 stop burnish procedure allows the friction materials to conform to the surface of the rotors and drums for improved stopping performance. The thermal conditioning of the friction materials during this process supports increased stability of braking effectiveness over a greater range of temperatures compared to when they are first installed.

V. New Rating System

As stated in the December 2015 RFC notice, NHTSA is planning to change the way NCAP rates vehicles for safety. An effective rating system: (a) provides consumers with easy-to-

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[156] http://www.edmunds.com/car-technology/brakes-drum-vs-disc.html .

[157] "Tech Tip: Brake Burnishing Procedures for New Brake Pads or Shoes," Bendix, http://www.brakeandfrontend.com/tech-tip-brake-burnishing-procedures-for-new-brake-pads-or-shoes/ accessed July 12, 2016.

[158] "Disc Pad and Brake Shoe Break-In (Burnish) Procedure," Federal-Mogul Document # 3519, Federal-Mogul, http://aftermarket.federalmogul.com/en-US/Technical/Documents/Brake%20Pad%20and%20Shoe%20Break-In%20Procedure.pdf accessed July 12, 2016.

[159] "Cleaning Disc Pad and Brake Shoe Break-In (Burnish) Procedure," Wagner, http://www.wagnerbrake.com/technical/technical-tips/break-in.html accessed July 12, 2016.

[160] "Disk Pad Break-in/Bedding-in/Burnishing," NAPA Brakes NB90051, http://www.napabrakes.com/magnoliaPublic/dms/bpi/napabrakes/pdf/DiscPadBreakinFinal.pdf accessed July 12, 2016.

understand information about vehicle safety, (b) provides meaningful comparative information about the safety of vehicles, and (c) provides incentive for the design of safer vehicles. As such, NHTSA believes an effective rating program will discriminate truly good performance in safety and spur continuous vehicle safety improvement. The current NCAP rating system comprises an overall vehicle rating (also known as the Vehicle Safety Score or Overall Vehicle Score), which is computed as the field-weighted scores from the full frontal crash, side crash (side MDB and side pole), and rollover resistance tests. It is based on a 5-star rating scale that ranges from 1 to 5 stars, with 5 stars being the highest. The current overall vehicle rating does not include assessment of existing crash avoidance technologies recommended under NCAP, which are listed as Recommended Technologies on the agency's Safercar.gov website.

In this notice, the agency discusses its tentative plans for a new overall vehicle rating, which will include individual star ratings for crashworthiness, crash avoidance, and pedestrian protection categories, without including star ratings for individual tests. Since there are many testing components that are planned for this NCAP upgrade and included in the new rating system, the agency believes that assigning stars to each individual testing component would confuse consumers. The agency notes that, although it has not yet conducted consumer testing on its new rating system, other NCAP programs such as Euro NCAP and Japan NCAP have similar vehicle safety performance programs (as planned for this NCAP upgrade). Thus, the agency believes that the three planned major star rating categories in the new rating system are not only necessary based on the safety need, but also useful to consumers based on success from other established NCAP programs worldwide. The agency may consider consumer testing on how to disseminate via the Monroney label vehicle safety information from the new rating system before it begins the rulemaking required to update the Monroney label to reflect planned program changes.

As mentioned in the December 2015 RFC notice, the agency tentatively plans to use half stars to allow better discrimination of vehicle safety so that consumers can make informed purchasing decisions. In general, although the agency has not conducted consumer testing on this planned change, NHTSA believes that the public is familiar with the half-star ratings concept as it is commonly found in other consumer product ratings. Furthermore, the agency believes that half stars are necessary in the new rating system because it allows better discrimination of vehicle safety performance. As will be discussed later in this notice, the use of half stars allows the agency to work with ten half-star bands in this NCAP upgrade instead of five full-star bands in the existing program.

The primary purpose of this discussion is to put forward information about how the ratings will tentatively be weighted in each of the three main categories and then combined into one overall vehicle rating. How those ratings will be displayed to the public on the Monroney label will be the subject of the future rulemaking required to update the Monroney label. Thus, although the agency has tentatively put forward the concept of only including three main category-level ratings and an overall vehicle rating, that is only the planned conceptual framework, not a definitive statement of how it will be displayed on the new Monroney label.

The next four paragraphs provide a high-level summary of the new rating system. As briefly mentioned, the new NCAP rating system consists of three sub-rating systems for crashworthiness, crash avoidance, and pedestrian protection, and a combined overall vehicle rating system. All four rating systems are based on a 5-star scale.

The crashworthiness sub-rating system is tentatively derived from the results of four crash tests (full frontal rigid barrier, frontal oblique, side MDB, and side pole) that use a combination of dummy types (THOR-50M, HIII-5F, WorldSID-50M, and SID-IIs) and seating locations (driver, front passenger, and rear passenger), depending on the crash test. Each dummy in each crash test is instrumented to measure some combination of displacement, force, angular velocity, and acceleration on several body regions. The conversion of measurement data to star rating follows this sequence:

1) Dummy measurements are converted to an injury criterion that is specific to the body region. For each injury criterion, there is an associated injury risk curve – a function to estimate the risk of certain type and severity of injury.
2) A scoring interval is determined for each body region (unique to each dummy and measurement method) that defines the upper and lower limits of the injury criterion. The planned intervals are derived, in part, by using the injury risk curves, values set in FMVSSs, and vehicle fleet assessment.
3) The value of the injury criterion is then converted to a point score, relative to its position within the upper and lower limits. Because each criterion measures forces on, or movement of, a body part, lower criterion values generally indicate better safety outcomes than higher values. In contrast, in the scoring system, more points are better than fewer points.
4) Each body part score is weighted as a percent of the total dummy score (i.e., the sum of the body part score weights equals 100 percent) and an entire dummy score is calculated. If any body part score was 0.0, then the entire dummy score is 0.0.

5) All dummy scores (8) from crash tests (4) are then weighted (totaling 100 percent), according to driver or passenger seating position, and summed.
6) The total sum of all points is then converted to a 5-star rating scale, where 10 points earns the first star and each additional 10 points earns a ½ star.

The crash avoidance sub-rating system is tentatively based on the presence and performance of nine crash avoidance technologies. The conversion of crash avoidance measurement data to star ratings follows this sequence:

1) Each crash avoidance technology is apportioned a certain percent of the total crash avoidance score, based upon their relative safety improvement potential estimates.
2) Each make-model vehicle is assessed based on each technology, obtaining some fraction of the maximum for that technology, depending on its equipage and performance.
3) The percentage total from the nine technologies is then converted to a 5-star rating, where every 20 percent earns 1 star. Half stars are not awarded in the crash avoidance sub-rating system.

The pedestrian protection sub-rating system is based on both crashworthiness and crash avoidance performance. The conversion of measurement data to star ratings follows this sequence:

1) Four impact tests are conducted (two headform, upper legform, and Flex-PLI), each at multiple locations of impact.
2) Measurements are converted to injury criteria and then to points in a manner similar to the crashworthiness sub-rating system described above.
3) For each of the three test types, the measurements from multiple test locations are then combined to provide one score per test type.

4) The three scores (one per test type) are then weighted (totaling 100 percent) and summed.
5) The total sum is then converted to a 2 ½-star rating scale.
6) In addition, two pedestrian crash avoidance technologies will be rated, in a manner similar to that described above for the crash avoidance sub-rating system.
7) The two pedestrian crash avoidance technology scores are then weighted (totaling 100 percent) and summed.
8) The total sum is then converted to a 2 ½-star rating scale.
9) The total pedestrian protection sub-rating system is then computed as the sum of stars achieved from the pedestrian crashworthiness and pedestrian crash avoidance tests.

The overall vehicle rating is then calculated from the scores obtained from the three sub-rating systems, based on an apportionment of the overall stars as follows: up to 2 ½ stars from crashworthiness, up to 2 stars from crash avoidance, and a potential ½ star from pedestrian protection categories. Each category's score is converted to the overall star rating using a simple scale, but that scale differs from the scale used for the sub-rating systems.

The planned approaches for determining the crashworthiness, crash avoidance, and pedestrian protection sub-rating systems are described in detail in the following sections. The agency reiterates that how the information obtained from the new rating system could be presented to the public is still subject to the rulemaking to update the Monroney label.

A. Crashworthiness Sub-Rating System

The agency examined 2010-2014 FARS data from real-world crashes representative of the tests to be included in this NCAP upgrade. The average fatalities per year over the time period examined were classified by crash direction and occupant location, and the results are shown in appendix I.

When the agency isolated fatal real-world crashes that are represented by the frontal and side crash modes being planned for use in this NCAP upgrade, it found that almost 60 percent of fatalities occurred in frontal crashes and just over 40 percent occurred in side crashes.[161] Therefore, the agency intends to use this weighting between frontal and side crash tests in the crashworthiness portion of its rating system. Under this plan, the results from the two frontal NCAP tests (oblique frontal and full frontal rigid barrier) would carry 60 percent of the crashworthiness rating weight and the results from the two side NCAP tests (MDB and pole) would carry 40 percent of the crashworthiness rating weight.[162]

Appendix I also shows that driver fatalities represent over 85 percent of real-world fatalities in this FARS data set, which is reflective of the fact that there is a driver in every crash. Weighting the driver in the crashworthiness rating this much, however, is not indicative of the actual risk to occupants in other seating positions when they are present in the vehicle and may not provide enough incentive (from a star rating perspective) for vehicle manufacturers to improve the safety offered to these other occupants. In its 2008 Final Decision notice establishing the existing NCAP safety ratings system, the agency reasoned that its ratings system should strike a balance between real-world exposure rates and its desire to encourage equal safety for all seating positions.[163] Based on this philosophy, and considering the overall weighting previously discussed, the agency tentatiavely plans to weight the driver in each test as 15 percent of the overall crashworthiness rating. Each remaining passenger (front or rear seat,

[161] See appendix I.
[162] In the current rating system, the combined crashworthiness rating is the weighted average of the scores from the frontal rigid barrier test (5/12), the side MDB and side pole tests (4/12), and the rollover resistance tests (3/12).
[163] From the 2008 Notice (73 FR 40036): "This is unlike GM's approach of applying significantly higher weight to the driver than the passenger based on occupancy rates in each seating position. NHTSA believes that GM's proposal would not encourage manufacturers to offer advanced safety systems to all seating positions, thereby resulting in reduced protection to some."

depending on the crash test) would be assigned a weight of 10 percent of the crashworthiness rating category. Figure 2 illustrates how all of the occupants and crash tests would be weighted in the overall crashworthiness rating that NHTSA is considering.

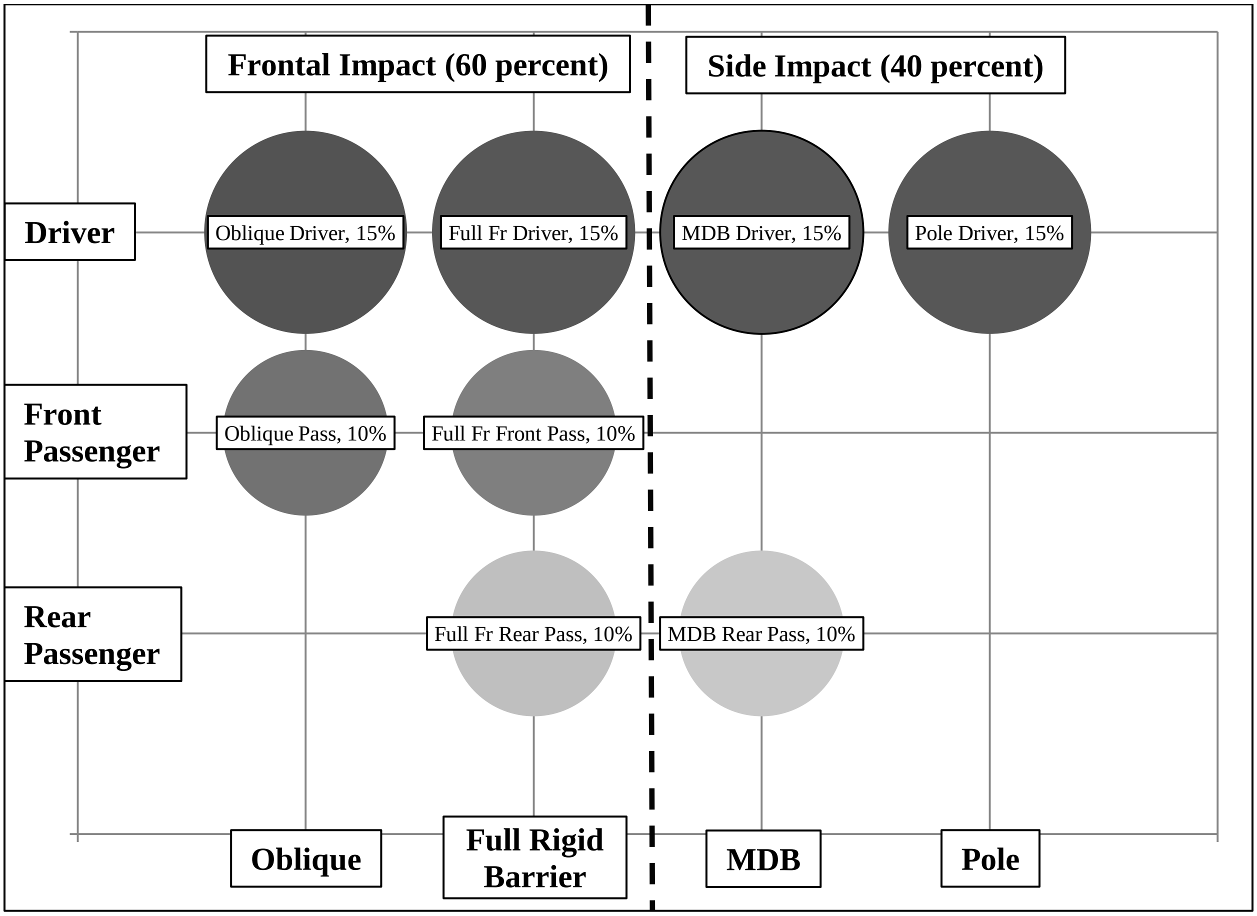

Figure 2 – Planned NCAP Overall Crashworthiness Rating System Weights by Occupant Location and Test Type

For the new crashworthiness rating category, the agency intends to assess occupant injury using the linear injury scale approach that was mentioned in the December 2015 RFC notice. This approach is new for NHTSA, but the basic concept behind it is used in the majority of other comprehensive vehicle safety consumer information programs around the world.[164] This approach is preferred in this NCAP upgrade because it allows more flexibility in the way NCAP

[164] Euro NCAP, Australasian NCAP, Japan NCAP, Latin NCAP, China NCAP, Korean NCAP, and IIHS all use some form of this approach for their ratings systems.

assesses injuries from various body regions, which allows the program to rate vehicles in a way that provides a better differentiation of safety. The agency would calculate a score for each body region by selecting upper and lower injury limits for each region and using those limits to translate an ATD test measurement linearly into a scale from 0 to 1. In other words, this approach normalizes the results from various body regions (which are collected on several different scales) to fit the same range. The normalized values, which are designed to range from 0 to 1, would then be combined to arrive at a numerical score that when combined with other occupant crashworthiness scores ultimately gets converted to a star rating. Full credit, or 1 point, would be achieved by each body region response meeting or performing better than the *lower* injury limit. No credit, or zero points, would be assigned if the *upper* limit for a body region response is met or if that limit is exceeded. Surpassing the upper limit on a given body region response would also mean zero points would be assigned to that occupant in that test condition. Values that fall in between the upper and lower limits for that body region would be assigned somewhere between 0 and full credit (1 point) by using a simple linear regression calculation (i.e., 1- (ATD measurement – lower limit)/(upper limit – lower limit)). Figure 3 below shows an example of this concept graphically for an injury assessment type.

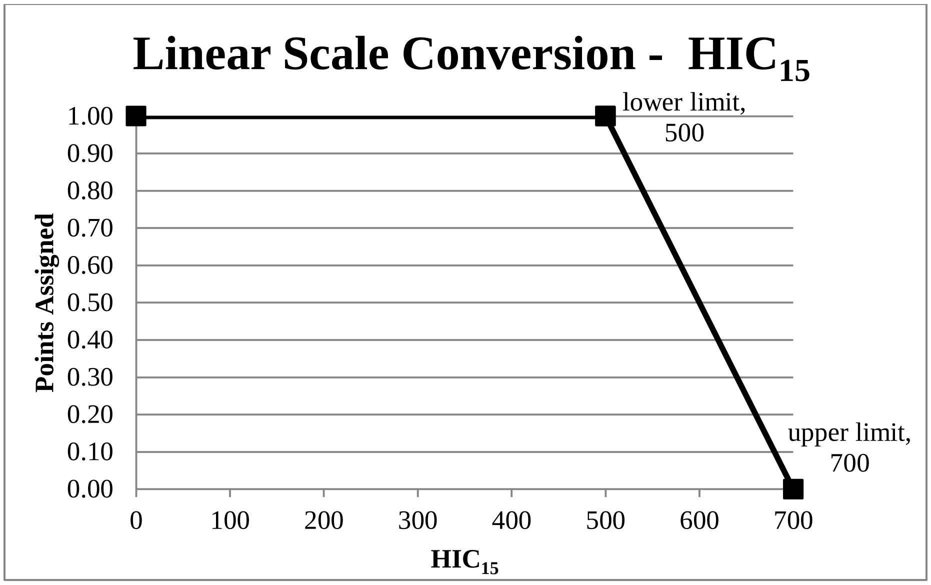

Figure 3 – Linear scale calculation example

The upper and lower limits were selected for reasons explained throughout the following sections. They were often informed by corresponding risk curves, associated experimental data, and the performance of vehicles in the current fleet, including what would likely be achievable with near-term improvements in vehicle safety systems. Where more than one criterion is available for an individual body region, the lowest scoring criterion (according to the 0 to 1 linear scale conversion) will be used in the rating calculation for that occupant.

The lower limit for each injury is typically being set at a value that the agency believes would maximize fleet differentiation and would be achievable – though not necessarily achieved yet in today's vehicle fleet.[165] In setting the lower limits, the agency also considered the lower threshold of injury observed in the experimental data used to create the respective injury risk curves, and the fleet and other data used to develop the underlying injury criterion. To determine the appropriate upper limits for various injury types, both experimental data and fleet data, as shown in several appendices to this document, were taken into account. In some cases, the upper

[165] The agency's supporting fleet test data is presented and discussed throughout this section.

performance limit for a body region is tied to a widely accepted IARV or an existing Federal regulatory value, or a predetermined percentage of that value. In others, the agency used a value from an associated risk curve to set the upper limit at a certain probability of risk. These upper and lower limits are discussed in detail, by each dummy and body region, in the sections that follow.

1. THOR-50M Upper and Lower Injury Limit Discussion

Many of the THOR-50M limits the agency is considering for use are based on the agency's analysis of the fleet data presented in appendices VII and VIII. This data includes a mixture of oblique and full frontal rigid barrier testing. Appendix XV shows how the THOR-50M fleet data from agency's full frontal and oblique testing compares to the upper and lower limits being considered throughout this section. NHTSA is requesting comment on these upper and lower injury limits, as well as the underlying risk curves presented in appendix II.

HEAD (HIC_{15} and BrIC)

For each THOR-50M dummy tested in the NCAP upgrade, the agency plans to choose from the worse of two injury measurements (with respect to the linear scale conversion) as the head performance for that occupant. Lower dummy response values are indicative of lower injury potential for real world occupants, so lower values are assigned higher points that would translate to higher ratings for that occupant. In contrast, higher dummy response values are indicative of increased injury potential for real world occupants and are assigned lower points that translate to lower ratings for that occupant. The agency plans to use AIS 3+ probability risks as reference points to determine the upper and lower limits for HIC_{15} and AIS 4+ injury risks for BrIC. Appendix II lists these two functions.

Lower Limit. The agency is considering a THOR-50M lower limit for HIC_{15} of 500. This equates to a 4.7 percent risk of an AIS 3+ skull fracture using the risk curve presented in appendix II. The lowest injury point in the original data set used to develop this risk curve occurred at a HIC of 450, so a lower limit of 500 is reasonable based on the level of injury observed experimentally.[166] The lower limit is also consistent with the one used by Euro NCAP, though the agency will assess HIC_{15} for the THOR-50M regardless of whether contact occurs.[167] The majority of the THOR-50M data presented in appendices VII and VIII fell below this lower limit, as illustrated in chart T1 of appendix XV.

The agency is considering a THOR-50M lower limit for BrIC of 0.71, or a 10 percent risk of AIS 4+ injury according to the formula presented in appendix II. The agency believes that it would: (1) provide the desired differentiation in fleet performance, (2) be achievable, and (3) be justifiable given the data used to develop the underlying risk curve. The fleet data presented in appendices VII and VIII demonstrate that a lower limit of 10 percent risk is achievable in frontal crash test occupant locations utilizing the THOR-50M ATD and would provide acceptable differentiation on the current fleet of vehicles as shown in chart T2 of appendix XV.

Upper Limit. The agency is considering a THOR-50M upper limit of HIC_{15} equivalent to the FMVSS No. 208 regulatory limit of 700. Though most of the occupants in appendices VII and VIII met the lower limit for HIC_{15}, several data points were higher than the upper limit, which shows some differentiation is possible in the current fleet. The data from those two

[166] Prasad P and Mertz H. (1985) "The Position of the United States Delegation to the ISO Working Group 6 on the Use of HIC in the Automotive Environment." SAE Government/Industry Meeting and Exposition, SAE paper no. 851246.; Hertz (1993) "A Note on the Head Injury Criteria (HIC) as a Predictor of the Risk of Skull Fracture." 37th Annual Proceedings of the Association for the Advancement of Automotive Medicine.
[167] EuroNCAP's approach differs in that it assesses HIC_{15} only in cases of hard contact, defined as a peak resultant head acceleration that exceeds 80g or if there is other evidence of hard contact. European New Car Assessment Programme, "Assessment Protocol – Adult Occupant Protection." Accessed July 2016, available at http://euroncap.blob.core.windows.net/media/20869/euro-ncap-assessment-protocol-aop-v703.pdf.

appendices is also included in chart T1 of appendix XV. While the THOR-50M is not a device that is currently used in regulatory testing, using the limit of 700 allows consistency between the frontal front seat dummies planned for use, which also includes the HIII-5F ATD. According to the AIS 3+ risk curve presented in appendix II, the injury risk associated with a HIC_{15} of 700 for the THOR-50M is 11.2 percent.

The agency is considering a THOR-50M upper limit for BrIC of 1.05, or a 50 percent risk of AIS 4+ injury according to the formula presented in appendix II. This risk level corresponds to the most frequently occurring value of BrIC at which injury occurred in the data set used to develop the risk function. It is believed that an upper limit of 50 percent risk would drive improvements to frontal air bag coverage for passengers, and both frontal and side curtain air bag coverage for drivers, to reduce the risk of brain injury in left oblique crashes. All of the full frontal THOR-50M drivers in the fleet data provided in appendix VII would fall below this upper limit, as all demonstrated a risk of AIS 4+ injury below 50 percent. Just over 50 percent of the oblique drivers and 25 percent of the oblique passengers in appendix VIII had BrIC values that fell below this value. Chart T2 in appendix XV shows that the limit is achievable and would provide differentiation in fleet performance using the data from appendices VII and VIII.

NECK (Nij)

Lower Limit. Per the fleet data presented in appendices VII and VIII, an Nij lower limit of 0.60 assessed using the AIS 3+ formula in appendix II fails to yield adequate fleet differentiation for the THOR-50M, as only two vehicles exceeded 10 percent risk. In addition, the experimental data presented in “Injury Criteria for the THOR 50th Male ATD” do not support this limit.[168] As demonstrated in that document, only one experimental failure occurred below Nij = 0.60, and the next weakest specimen failed at a Nij = 0.73. As such, attempting to drive fleet performance below 0.60, wherein AIS 3+ injuries generally did not occur in PMHS specimens, may not be reasonable. Instead, the agency is considering setting the lower limit for the THOR-50M at a 10 percent risk of AIS 2+ injury (Nij = 0.39). According to "Injury Criteria for the THOR 50th Male ATD," four experimental specimens (seven percent) sustained AIS 2+ injuries with Nij less than or equal to 0.39, and seven (13 percent) sustained AIS 2+ injuries with Nij less than or equal to 0.60 (the AIS 3+ 10 percent risk threshold).[169] As such, setting the THOR-50M lower neck injury limit to 10% risk of AIS 2+ injury (Nij = 0.39) would be consistent with experimentally-produced injuries in PMHS. In addition, several THOR-50M responses in agency testing were lower than this lower limit. The agency believes this limit provides adequate fleet differentiation using Nij, as shown in chart T3 of appendix XV and the corresponding fleet data in appendices VII and VIII.

Upper Limit. For values of Nij for the THOR-50M, a 50 percent risk of AIS 2+ injury (an Nij of 0.80 according to the formula in appendix II) also closely approximates a 25 percent chance of AIS 3+ injury (an Nij of 0.85 according to the formula in appendix II). Because none of the fleet data presented in appendices VII and VIII exhibited THOR-50M Nij values above Nij = 0.80 or 0.85, the agency believes an Nij of 0.85 is a good limit for awarding zero points for a THOR-50M neck assessment. The THOR-50M Nij data from appendices VII and VIII, along with the upper and lower limits the agency is considering, is plotted in chart T3 of appendix XV.

CHEST (Peak Resultant Deflection)

[168] "Injury Criteria for the THOR 50th Male ATD," in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.
[169] Ibid.

Lower Limit. According to the injury risk curve presented in appendix II, a 10 percent risk of THOR-50M AIS 3+ thoracic injury equates to 26.16 mm of peak resultant deflection. This risk level is also below the average predicted risk in the oblique fleet vehicle data presented in appendix VIII and below the lowest injury risk in any of the full frontal crash test results shown in appendix VII. Given both the experimental and the fleet data, the agency is considering a lower limit of 25 percent risk as determined using the formula in appendix II (equivalent to 37.9 mm of peak resultant deflection). Experimental data presented in "Injury Criteria for the THOR 50th Male ATD" showed that the two lowest deflections in injury cases (age-adjusted) were 30 mm (14 percent risk) and 45 mm (37 percent risk), making 25 percent risk a reasonable lower limit.[170] This limit also provides a good target for full-credit performance because it is achievable in at least one vehicle in two of the three frontal crash test occupant locations utilizing the THOR-50M ATD. None of the oblique drivers in appendix VIII would achieve full credit (1 point) for the chest deflection criterion using this limit, but this is somewhat expected given this is a new test mode with a new ATD. The data from appendices VII and VIII is also illustrated in chart T4 of appendix XV.

Upper Limit. The agency is considering 52.3 mm for the upper limit of chest peak resultant deflection, as this would be a level equivalent to a 50 percent risk of AIS 3+ injury per the formula in appendix II. Based on the fleet data from appendices VII and VIII, chart T4 in appendix XV shows that chest deflection data for nearly half of the THOR-50M drivers and all but one of the THOR-50M right front passengers fell below this limit. A 50 percent risk level provides differentiation and is achievable.

ABDOMEN (Peak Compression)

[170] Ibid.

Lower Limit. A lower limit of peak abdomen compression is not being recommended at this time due to biofidelity and instrumentation limitations. The quantitative biofidelity evaluation of the THOR-50M demonstrated a poor external biofidelity rating in the lower abdomen rigid bar impact condition and a marginal external biofidelity rating for the abdomen body region overall.[171] Due to this, a lower performance limit for abdomen response is not being recommended for the THOR-50M.

Upper Limit. An upper performance limit is being considered for the THOR-50M abdomen compression as a protection against unintended restraint system loading patterns. The agency is considering an upper limit of 88.6 mm. An upper limit at the 50 percent risk level of AIS 3+ abdomen injury, according to the risk curve in appendix II, equates to a peak abdominal compression of 88.6 mm. The agency believes this limit is achievable, as it is well above the peak abdomen compression measured in any of the THOR-50M validation tests listed in appendix VII and appendix VIII. The THOR-50M abdomen data from those tests is repeated in chart T5 of appendix XV.

KNEE/THIGH/HIP (Acetabulum Force and Femur Force)

For each THOR-50M dummy tested in NCAP, the agency would choose from two injury criteria to assign points estimating the knee/thigh/hip (KTH) injury risk to that occupant. With respect to the linear scale conversion, the worst one of the following four responses would be used to represent the KTH portion of the rating assigned to that THOR-50M occupant: (1) left resultant acetabulum force, (2) right resultant acetabulum force, (3) left peak compressive femur force, and (4) right peak compressive femur force. As shown in the list of THOR-50M risk

[171] "THOR-50M Biofidelity Report" in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

curves in appendix II, the agency plans to use an AIS 2+ acetabulum force assessment and an AIS 2+ femur force assessment to determine the lower and higher limits.

Lower Limit. For both of the KTH injury criteria, using the AIS 2+ acetabulum force and femur force risk curves listed in appendix II, the agency is considering using lower limits of 10 percent injury risk. A femur force lower limit at the 10 percent risk level corresponds to a peak compressive force of 5,331 N. A majority of the fleet data presented in appendix VII and VIII, and plotted on chart T7 of appendix XV, would achieve full credit based on this lower limit. An acetabulum force lower limit at the 10 percent risk level corresponds to a peak force of 2,583 N. The weakest injured specimen presented in "Injury Criteria for the THOR 50th Male ATD" occurred at forces just above this 10 percent risk level.[172] As such, it is a well-supported threshold to target for minimizing the risk of hip fracture. Roughly half of the data presented in appendices VII and VIII would fall below this lower limit, as shown when the THOR-50M acetabulum results are plotted in chart T6 of appendix XV.

Upper Limit. For both of the KTH injury criteria, using the AIS 2+ acetabulum force and femur force risk curves presented in appendix II, the agency is considering upper limits at 50 percent risk because the agency believes they provide acceptable differentiation and are achievable. An upper limit at the 50 percent risk level corresponds to a peak compressive femur force of 8,588 N when using the AIS 2+ formula presented in appendix II. All but one of the THOR-50M fleet data points presented in appendices VII and VIII, and shown in chart T7 of appendix XV, would fall below this upper limit, with the exception being a single oblique driver observation. An upper limit at the 50 percent risk level also corresponds to a peak resultant acetabulum force of 3,486 N when using the AIS 2+ formula presented in appendix II. As shown

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[172] "Injury Criteria for the THOR 50th Male ATD," in NHTSA-2015-0119, available at http://www.regulations.gov/docket?D=NHTSA-2015-0119.

in chart T6 of appendix XV, a majority of the observations from the THOR-50M acetabulum data presented in appendices VII and VIII would also fall below that upper limit.

LOWER LEG (Upper Tibia Force, Lower Tibia Force, and Tibia Bending Moment)

For each THOR-50M tested in NCAP, the agency would choose from three criteria to assign points estimating the lower leg injury risk to that occupant. With respect to the linear scale conversion, the worst one of the following eight responses and/or calculated injury assessments would be used to represent the lower leg portion of the rating assigned to that THOR-50M occupant: (1) left upper tibia force, (2) right upper tibia force, (3) left lower tibia force, (4) right lower tibia force, (5) left upper tibia bending moment, (6) right upper tibia bending moment, (7) left lower tibia bending moment, (8) right lower tibia bending moment.

Lower Limit. The agency is considering lower limits at 10 percent risk levels for all of the THOR-50M lower leg injury criteria. For the lower tibia, a lower limit of 10 percent risk corresponds to a force of 3,573 N when assessed using the AIS 2+ risk curve presented in appendix II. A lower tibia lower limit of 10 percent (F_z = 3,573 N) is slightly below the minimum PMHS failure load for male specimens of 4,460 N demonstrated in "Injury Criteria for the THOR 50th Male ATD."[173] For the upper tibia, a lower limit of 10 percent risk corresponds to a force of 4,235 N when assessed using the AIS 2+ risk curve presented in appendix II. For the upper tibia, a 10 percent risk (F_z = 4,235) is slightly higher than the minimum failure load in the experimental data presented in "Injury Criteria for the THOR 50th Male ATD."[174] That report shows that while the lowest failure load was 3,800 N, the next highest failure load was 5,800 N. For the tibia bending moment, a lower limit at 10 percent risk corresponds to a moment of 178

[173] Ibid.
[174] Ibid.

Nm when assessed using the AIS 2+ risk curve presented in appendix II. For the tibia bending moment, a lower limit at 10 percent risk (M_y = 178 Nm) is consistent with the minimum resultant moments shown in the experimental data (170 Nm); three out of 63 experimental failures (5 percent) occurred below 178 Nm.[175] A lower leg lower limit of 10 percent for all three criteria therefore has a basis in the experimental data the agency has evaluated. The majority of the THOR-50M test data presented in appendices VII and VIII would receive full credit (1 point) given a 10 percent lower limit for all lower leg criteria, making it achievable; however, not all would receive full credit, as shown in charts T8, T9, and T10 of appendix XV. That allows for some differentiation in the fleet.

Upper Limit. For the lower leg criteria upper limits, a value of 50 percent does not achieve the desired differentiation of fleet performance for the vehicles shown in appendix VII or VIII, so the agency is considering a more stringent limit of 25 percent for each lower leg criteria. The agency believes such a limit is achievable given this data. For the lower tibia, the 25 percent risk limit corresponds to a force of 5,861 N according to the AIS 2+ function in appendix II. For the upper tibia axial force, the 25 percent risk level corresponds to a force of 5,577 N according to the AIS 2+ function in appendix II. For the tibia bending moment, the 25 percent risk level corresponds to a moment of 240 Nm according to the AIS 2+ function in appendix II.

The experimental data discussed in "Injury Criteria for the THOR 50th Male ATD" shows that for the lower tibia, approximately 25 percent of the injured males had lower tibia forces at or below a 25 percent risk level (Fz = 5,861) based on the formula in appendix II.[176] For the tibia bending moment, a similar percentage of experimental failures occurred at or below a 25 percent

[175] Ibid.

[176] Ibid.

injury risk level (My = 240 Nm) based on the risk curve in appendix II. Thus, for these two measures, an upper limit of 25 percent is consistent with both the experimental data and fleet data. For the upper tibia, the same does not hold true. For upper tibia axial force, the 25 percent risk level, according to the formula in appendix II, corresponds to 5,577 N. In the experimental data, only a single PMHS specimen out of 14 failed at a load below 5,577 N. Nonetheless, given that none of the THOR-50M occupants in appendices VII and VIII had lower leg responses that were higher than the 25 percent upper limit being considered, raising this limit does not appear that it would be beneficial for fleet differentiation. Thus, the agency is planning to use the same risk level for the upper tibia axial force upper limit (25 percent) as the other lower leg criteria. Lower leg results from the agency's THOR-50M testing are plotted in charts T8, T9, and T10 of appendix XV.

2. HIII-5F Upper and Lower Injury Limit Discussion

Some of the HIII-5F limits the agency is considering for use are based on the agency's analysis of the fleet data presented in appendix VII. Others are based on existing IARVs, such as those in FMVSS No. 208. Appendix XV shows how the front and rear seat HIII-5F data from agency full frontal testing compares to the upper and lower limits being considered throughout this section. NHTSA is requesting comment on these upper and lower injury limits as well as the underlying risk curves presented.

<u>HEAD (HIC15 and BrIC)</u>

Similar to the approach used for the THOR-50M, for each HIII-5F dummy tested in the front seat of NCAP, the agency would select from the worst (with respect to the linear scale conversion) of two injuries measured by the dummy to assign points estimating the head injury risk to that occupant. As shown in the list of HIII-5F risk curves in appendix III, the agency is considering an AIS 3+ HIC_{15} assessment and an AIS 4+ BrIC assessment. For the rear seat HIII-5F, the agency is considering only assessing HIC_{15} if head contact is observed through chalk, video, or other data analysis. If no head contact occurs, the HIC_{15} measurement would not factor into the rear seat HIII-5F's score. BrIC would not be assessed for the rear seat HIII-5F.

Lower Limit. The agency is considering setting a HIII-5F lower limit for HIC_{15} of 500. This equates to a 4.7 percent risk of an AIS 3+ skull fracture using the risk curve presented in appendix III. This value is also consistent with the limit used by EuroNCAP.[177] All of the front seat HIII-5F HIC_{15} data presented in appendix VII would meet this lower limit as shown on chart H1 in appendix XV.

The agency is considering setting a HIII-5F lower limit for BrIC of 0.71, or a 10 percent risk of AIS 4+ injury according to the formula presented in appendix III. This harmonizes the HIII-5F BrIC lower limit with that of the THOR-50M. With the exception of two data points, most of the HIII-5F BrIC responses in appendix VII and on chart H2 in appendix XV were less than this lower limit and would achieve full points. The agency believes this limit would provide the desired differentiation in fleet performance, is achievable, and is justifiable given the data used to develop the underlying risk curve.

Upper Limit. The agency is considering setting the HIII-5F upper limit of HIC_{15} at the FMVSS No. 208 regulatory limit of 700. According to the AIS 3+ risk curve presented in appendix III, the injury risk associated with a HIC_{15} of 700 is 11.2 percent. No front seat HIII-5F occupants in appendix VII, or as shown in chart H1 of appendix XV, exhibited responses higher

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[177] European New Car Assessment Programme, "Assessment Protocol – Adult Occupant Protection." Accessed July2016, available at http://euroncap.blob.core.windows.net/media/20869/euro-ncap-assessment-protocol-aop-v703.pdf.

than this limit. In addition, no rear seat HIII-5F occupants in that data set experienced head contact during testing, so head injury would not be assessed.

The agency is considering setting the HIII-5F upper limit for BrIC at 1.05, or a 50 percent risk of AIS 4+ injury according to the formula presented in appendix III. This risk level corresponds to the most frequently occurring value of BrIC at which injury occurred in the data set used to develop the risk function.[178] The agency believes that an upper limit of 50 percent risk will drive improved right front air bag performance and provide a balance between oblique and full frontal crash modes. It is also consistent with the planned upper limits for BrIC used with the THOR-50M. None of the right front seat HIII-5F occupants in appendix VII and as shown in chart H2 of appendix XV exhibited responses greater than the upper limit being considered for BrIC.

NECK (Nij)

Lower Limit. The agency is considering setting the Nij lower limit for the front seat HIII-5F at a value of 0.5, which equates to a 5.1 percent chance of injury given the AIS 3+ formula presented in appendix III. Most of the occupants in appendix VII and in chart H3 of appendix XV would achieve full credit using this lower limit. As stated previously, the agency will not be evaluating Nij for the HIII-5F in the rear seat.

Upper Limit. The agency is considering setting the Nij upper limit for the front seat HIII-5F at the FMVSS No. 208 regulatory limit of 1.0, which equates to a 31.9 percent chance of injury given the AIS 3+ formula presented in appendix III. As shown in chart H3 of appendix

[178] Takhounts, E. G., Hasija, V., Moorhouse, K., McFadden, J., & Craig, M., “Development of Brain Injury Criteria (BrIC),” Proceedings of the 57th Stapp Car Crash Conference, Orlando, FL, November 2013, available at http://www.nhtsa.gov/DOT/NHTSA/NVS/Biomechanics%20&%20Trauma/SIMon/Stapp2013%20Takhounts.pdf.

XV, none of the HIII-5F responses from the agency's full frontal testing were higher than this upper limit.

CHEST (Chest Deflection)

Lower Limit. The agency is considering setting the chest deflection lower limit for both the front and rear seat HIII-5F at 25 mm, which equates to a 5 percent chance of injury given the AIS 3+ formula presented in appendix III. Most of the front seat HIII-5F data in appendix VII and shown in chart H4 of appendix XV would receive full credit for the chest injury assessment if this limit was selected. None of the rear seat data would achieve full credit if this limit is selected, but this is to be expected given that frontal crash testing in this seating position is a new area of exploration for NCAP.

Upper Limit. The agency is considering setting the chest deflection upper limit for both the front seat and rear seat HIII-5F at the FMVSS No. 208 regulatory limit of 52 mm. This equates to a 52.5 percent chance of injury given the AIS3+ formula listed in appendix III. Only one chest deflection data point in appendix VII and chart H4 of appendix XV was higher than this limit, making the limit achievable while also allowing for fleet differentiation.

ABDOMEN (Submarining Assessment)

Abdomen injury will only be assessed for the rear seat HIII-5F. Limits based on a risk curve are not being considered; rather, NCAP is seeking comment on its inclusion of a submarining assessment to assess abdominal injuries for the rear seat HIII-5F occupant. Determination of a submarining event for a rear seat HIII-5F in a full frontal NCAP test would be treated the same as exceeding any upper limit in this system, that is, it results in that occupant receiving zero points towards that vehicle's rating.

Lower Limit. A lower limit is not being considered for the assessment of abdomen injury for the rear seat HIII-5F. Occupants that do not exceed the upper limit are not assigned points, nor are they penalized. The abdomen results would only affect the score if the upper limit is exceeded.

Upper Limit. The abdomen would only be evaluated for the rear seat HIII-5F. A combination of the anterior superior iliac spine (A.S.I.S.) load cell and video review will be used to determine a submarining event. A.S.I.S. load cell data showing a decreasing rate of ilium bone force of 1,000,000 N/second or more will initiate a video review. This approach is similar to the one used by Japan NCAP to evaluate rear seat occupants.[179] An analysis and discussion of the agency's testing observations regarding submarining events with a rear seat HIII-5F is included in a report to this docket.[180] Occurrence of a submarining event will be treated as exceeding the upper limit for the abdomen.

FEMUR (Femur Axial Force)

The agency is considering assessing femur injury for the front seat HIII-5F but not for the rear seat HIII-5F.

Lower Limit. A lower limit is not being considered for the assessment of femur injury for the front seat HIII-5F. As the data in appendix VII shows, the mid-track positioning of this ATD results in very low femur responses.

Upper Limit. The agency is considering a 6,805 N femur upper limit for the front seat HIII-5F as a compliment to FMVSS No. 208. This equates to a 35.2 percent chance of injury given the AIS 2+ formula listed in appendix III.

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[179] "2014 Offset Frontal Collision Safety Performance Test Procedure" Japan NCAP. Accessed July 2016, available at http://www.nasva.go.jp/mamoru/en/download/other_download.html.
[180] "Occupant Response Evaluation in NCAP Pilot Full Frontal Rigid Barrier Impact Crash Testing" in NHTSA-2015-0119, available at http://www.regulations.gov/docket?D=NHTSA-2015-0119

A summary of the upper and lower limits being considered for both the THOR-50M and the HIII-5F is presented in table 2 below.

Table 2 – Summary of upper and lower injury limits for use with the THOR-50M and the HIII-5F linear scale approach

		THOR-50M		HIII-5F	
Body Region	**Injury Criteria**	**Lower Limit Value (Full credit, 1 point)**	**Upper Limit Value (No credit, 0 points)**	**Lower Limit Value (Full credit, 1 point)**	**Upper Limit Value (No credit, 0 points)**
Head	**HIC_{15}**	500	700	500[3]	700[3]
	BrIC	0.71	1.05	0.71[1]	1.05[1]
Neck	**Nij**	0.39 (AIS 2+)	0.85 (AIS 3+)	0.5[1]	1[1]
Chest	**Deflection**	37.9 mm	52.3 mm	25 mm	52 mm
Abdomen	**Compression**	NA	88.6 mm	NA	Submarining Assessment[2]
Femur/Knee	**Peak Resultant Acetabulum Force**	2,583 N	3,486 N	NA	NA
	Peak Axial Femur Force	5,331 N	8,588 N	NA	6,805 N[1]
Lower Leg	**Upper Tibia Axial Force**	4,235 N	5,577 N	NA	NA
	Lower Tibia Axial Force	3,573 N	5,861 N	NA	NA
	Tibia Bending Moment	178 Nm	240 Nm	NA	NA

[1] Assessed for the front seat HIII-5F only.
[2] Assessed for the rear seat HIII-5F only.
[3] For the rear seat HIII-5F, assessed only in cases of event head contact.

3. WorldSID-50M Upper and Lower Injury Limit Discussion

Similar to the THOR-50M ATD, many of the upper and lower injury limits that the agency is considering using for the WorldSID-50M ATD were determined by reviewing the experimental data that was used to develop the related risk curves. The primary goal of NCAP is to provide consumers with meaningful and comparative safety information, and the upper and lower performance limits were set with this goal in mind. NHTSA is requesting comment on these upper and lower injury limits, as well as the underlying risk curves presented in the accompanying appendices.

HEAD (HIC15 and BrIC)

For each WorldSID-50M dummy tested in NCAP, the agency will choose from the worst of two injuries measured by the dummy to assign points estimating the head injury risk to that occupant. As shown in the list of WorldSID-50M risk curves in appendix IV, and as detailed earlier in the injury criterion section of this notice for the side impact program, an AIS 3+ HIC_{15} assessment and an AIS 4+ assessment of BrIC responses are planned.

Lower Limits. The agency is considering setting the WorldSID-50M lower limit for HIC_{15} at 500. This equates to a 4.7 percent risk of an AIS 3+ skull fracture using the risk curve presented in appendix IV. This lower limit is consistent with the lower performance limit used by Euro NCAP for the program's side MDB and pole tests.[181] Also, as stated in the THOR-50M head limit discussion, the first injury in the PMHS experimental data used to develop the HIC risk curve was observed at a HIC_{15} of 450.[182,183]

As is shown in chart W1 in appendix XV, WorldSID-50M driver ATDs in five of the six vehicles in the side pole validation tests, and all six vehicles in the side MDB validation tests, had HIC_{15} readings that fell below the lower limit of 500. Although nearly all validation test vehicles exposed to the agency's side impact tests had HIC_{15} readings that were less than the lower bound of 500, the agency believes that this lower limit is appropriate. HIC readings have factored into side NCAP ratings since the program was last upgraded for MY 2011 vehicles, and have also been part of FMVSS No. 214 since it was last updated in 2007. Vehicle manufacturers

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[181] European New Car Assessment Programme, "Assessment Protocol – Adult Occupant Protection." Accessed July 2016, available at http://euroncap.blob.core.windows.net/media/20869/euro-ncap-assessment-protocol-aop-v703.pdf.

[182] Prasad P and Mertz H. (1985) "The Position of the United States Delegation to the ISO Working Group 6 on the Use of HIC in the Automotive Environment." SAE Government/Industry Meeting and Exposition, SAE paper no. 851246.

[183] Hertz (1993) "A Note on the Head Injury Criterion (HIC) as a Predictor of the Risk of Skull Fracture." 37th Annual Proceedings of the Association for the Advancement of Automotive Medicine.

have responded, in turn, by improving the head protection afforded in side impact crashes such that low HIC_{15} readings in the side validation tests were expected. In consideration of these points, the agency does not want to arbitrarily set a lower bound for the HIC_{15} injury criterion that is less than what is necessary and feasible, since differentiation between vehicles below what could already be considered to be a low threshold (i.e., 5 percent chance of head injury) would not be very meaningful.

For the WorldSID-50M, the agency is considering setting a lower limit for BrIC at 0.65, or a five percent risk of AIS 4+ injury according to the formula presented in appendix IV for the WorldSID-50M. Based on the validation test data provided in appendices IX, XI, and XV, the agency believes that this threshold is achievable and will permit differentiation in performance. Furthermore, the agency believes that this limit is justifiable given the data used to develop the underlying risk curve.[184] The validation test data demonstrates that a lower limit of 5 percent risk was achievable for four driver dummies in the MDB test and three driver dummies in the side pole test.

Upper Limits. The agency is considering a HIC_{15} upper limit for the WorldSID-50M ATD of 700. Using this limit is not only consistent with that planned for the THOR-50M in frontal NCAP, but it is used by Euro NCAP in the side pole and MDB tests. According to the AIS 3+ risk curve presented in appendix IV, the injury risk associated with a HIC_{15} of 700 is 11.2 percent.

The agency is considering an upper limit for BrIC for the WorldSID-50M ATD of 0.85, which is equivalent to a 25 percent risk of AIS 4+ injury according to the formula presented in appendix IV. As with the lower limit for BrIC, the agency believes that this limit is justifiable,

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184 "Injury Criteria for the THOR 50th Male ATD," in NHTSA-2015-0119, available at https://www.regulations.gov/docket?D=NHTSA-2015-0119.

since the data set used to develop the underlying risk curve showed a notable amount of injury at this risk level. The agency believes that setting the upper limit for BrIC at 25 percent risk provides a large enough range between the upper and lower limits to achieve an acceptable level of fleet differentiation such that vehicle manufacturers trending towards the higher end of the range should be encouraged to make improvements to side curtain air bags to further reduce head rotation in side MDB and pole crashes. Although only one of the drivers in the side MDB test registered a BrIC reading that fell within the range defined by the upper and lower limits as seen in chart W2 in appendix XV, three drivers in the side pole test fell within this range. Furthermore, all of the WorldSID-50M drivers in the side MDB and side pole validation tests recorded BrIC readings that that were lower than the upper limit. These findings suggest that the planned limits are achievable for side impact crashes and will provide acceptable fleet differentiation.

The agency has chosen to set a different range for BrIC in its side NCAP tests compared to its frontal NCAP tests because the agency's validation tests showed that vehicles from the current fleet typically have robust side curtain air bags that effectively limit not only head translation but also head rotation towards the impacting vehicle or pole. Conversely, the current fleet does not yet have adequate countermeasures to limit head rotation in the frontal barrier and oblique tests. Driver dummies in the side NCAP tests, therefore, averaged much lower BrIC readings.

In comparing the associated injury risks for the HIC_{15} readings recorded during the side MDB and pole validation tests to those for BrIC, the agency believes that the HIC_{15} injury criterion will likely have minimal effect on the ratings for the majority of vehicles subjected to side NCAP crash tests in the future. Nevertheless, the agency maintains that it should retain this criterion in the ratings for NCAP's side program. This will ensure vehicle manufacturers remain diligent in providing adequate side impact head protection in new vehicles, especially given the changes anticipated for side curtain air bags to improve dummy performance in either the IIHS small overlap frontal test or the agency's frontal oblique test. HIC_{15} and BrIC are critical to monitor simultaneously in side impact crash tests in order to protect the head from injuries resulting from both linear and angular motion of the head.

SHOULDER (Maximum Force)

As mentioned in the injury criteria section for the WorldSID-50M of this notice, the agency plans to adopt only an upper performance limit for maximum shoulder force in the lateral direction.

Lower Limit. The agency does not wish to assess shoulder injury risk in such a way that would encourage manufacturers to subject the more vulnerable thoracic region to excessive loading. As such, the agency believes it is inappropriate to adopt a lower limit for maximum shoulder force at this time.

Upper Limit. The agency is considering an upper limit for maximum shoulder force of 2.5 kN, which is equivalent to 50 percent risk of AIS 2+ injury for a 45-year-old. As mentioned previously in the injury criteria section, NHTSA's goal is to balance crash loads to the occupant. The agency's recent validation tests showed maximum shoulder forces ranging from 1.6 kN to approximately 2.2 kN in the side pole validation tests and 360 N to 1.7 kN in the side MDB tests. The highest load, 2.2 kN, corresponds to 23 percent risk of AIS 2+ injury for a 45-year-old occupant. In contrast, the 3.0 kN upper performance limit adopted by Euro NCAP and the side pole GTR working group corresponds to a 93 percent risk. NHTSA believes that this risk is very high, particularly when compared with other upper performance limits adopted for the updated

NCAP. Therefore, the agency believes it is more appropriate to adopt a 2.5 kN upper performance limit. As seen in chart W3 in appendix XV, the validation testing demonstrated that this limit is achievable.

CHEST (Maximum Thoracic or Abdominal Deflection Indicative of Skeletal Injury)

As mentioned in the injury criteria section for the WorldSID-50M, the agency is considering adopting an AIS 3+ risk curve, presented in appendix IV, for maximum thoracic/abdomen skeletal deflection. The lower limit for this criterion will be set to reflect the risk for a 67-year-old, and the upper limit will be set to reflect the risk for a 45-year-old. Not only is this a similar approach to that adopted by Euro NCAP for the thorax in the program's side impact tests, but it is also an avenue that the agency sees as being necessary in order to differentiate vehicle performance, particularly for the side pole tests, as these had a larger deflection range. Adopting the stated approach should allow the agency to realize larger data spreads within the established lower and upper limits. Assessments will be based on the worst-performing thoracic or abdominal rib (i.e., the one with the greatest deflection).

Lower Limit. The agency is considering a lower limit for thoracic/abdominal skeletal injury risk of 27 mm, which corresponds to 10 percent risk for a 67-year-old. The validation testing results show that all six of the WorldSID-50M side MDB drivers and one side pole driver recorded maximum thoracic/abdomen rib deflection readings that were less than 27 mm. However, the agency does not believe there is merit to setting an even lower risk threshold for this criterion, even if many of the validation test vehicles showed that 10 percent risk is currently achievable, because the PMHS experimental data used to develop the risk curve for a 67-year-old did not show injuries for lower levels of rib deflection.[185] Furthermore, maximum rib deflection readings for the driver ATD in the side pole validation tests ranged from a minimum of 24 mm to a maximum of 61 mm. This latter value corresponds to 63 percent risk for the AIS 3+ curve scaled for a 45-year-old, which is the age that will dictate the upper limit for this criterion. Considering the wide range in performance (i.e., 10 to 63 percent risk) for the side pole tests, setting the lower limit at 10 percent risk should still be adequate to differentiate among vehicle models for this test mode.

Upper Limit. The agency is considering an upper limit for thoracic/abdominal skeletal deflection of 50 mm, or a level equivalent to approximately 30 percent risk of AIS 3+ injury for a 45-year-old, per the formula in appendix IV. A 30 percent chance of thoracic injury corresponds to 31 mm of deflection for a 67-year-old. The agency's side pole validation testing showed that five WorldSID-50M drivers would have exceeded an upper limit of 31 mm. Therefore, the agency believes, as mentioned in the injury criteria section of this notice for the WorldSID-50M, that it is most reasonable, given the range in deflections recorded, to use the 45-year-old risk curve to dictate the upper threshold. This limit will permit acceptable fleet differentiation, and thereby incentivize improvements, and will also harmonize with criteria used for Euro NCAP's side impact tests.

ABDOMEN (Maximum Abdominal Deflection Indicative of Soft Tissue Injury)

As mentioned earlier in this notice in the injury criteria section for the WorldSID-50M, the agency plans to assess soft tissue abdominal injuries at the AIS 2+ severity level for a 67-year-old.

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[185] See "WorldSID 50th Percentile Male Side Impact Dummy Injury Risk Functions for the New Car Assessment Program (NCAP)" in NHTSA-2015-0119, available at http://www.regulations.gov/docket?D=NHTSA-2015-0119.

Lower Limit. Maximum abdominal rib deflection readings ranged from 7 mm to 22 mm in the agency's side MDB validation tests and from 22 mm to 45 mm in the side pole tests. At the AIS 2+ severity level, 45 mm of deflection corresponds to 17 percent risk of abdominal soft tissue injury for a 67-year-old. Because soft tissue injuries are not shown in the PMHS experimental dataset until approximately 42 mm of abdominal rib deflection, and the agency's highest abdominal rib deflection reading was 45 mm, the agency tentatively concludes that a lower limit for this criterion is not necessary to incentivize meaningful progress in occupant safety.[186] As such, the agency plans to adopt only an upper limit for this criterion.

Upper Limit. Based on the range of abdominal rib deflection readings recorded in the validation tests and the experimental data used to develop the risk function for abdominal soft tissue injuries, the agency is considering adopting a limit for abdominal soft tissue injuries that corresponds to 26 percent risk for a 67-year-old. This is equivalent to 47 mm of deflection. Although the maximum abdominal rib deflection readings from the agency's validation tests corresponded to less than 17 percent risk of AIS 2+ soft tissue injuries for a 67-year-old, the agency believes that it is still important to incorporate this criterion to ensure that manufacturers are mitigating this type of injury.

PELVIS (Maximum Pubic Force and Resultant Sacroiliac Force)

Similar to the head injury criteria, the agency will choose from the worst of two injuries measured by the WorldSID-50M to assign points estimating the risk of pelvis injury for an occupant. As shown in the list of WorldSID-50M risk curves in appendix IV, and as detailed earlier in the injury criteria section of this notice for the side impact program, AIS 2+ assessments for pubic force and sacroiliac resultant force adjusted for a 67-year-old are planned.

[186] Ibid.

Lower Limit. For the WorldSID-50M, the agency is considering a lower limit of 1,330 N for pubic force, which represents five percent risk of AIS 2+ injury. As is shown in chart W7 of appendix XV, WorldSID-50M driver ATDs in five of the six vehicles in the side pole validation tests and five of the six vehicles in the side MDB validation tests had pubic force readings that were less than 1,330 N. However, the agency believes that this lower limit is appropriate, as only two PMHS injuries were seen in the experimental data set for pubic force at lower force levels.[187] The agency does not want to set a lower bound that is less than what is necessary and feasible, since differentiation between vehicles below what could already be considered to be a low threshold (i.e., five percent chance of pelvis injury) would not be very meaningful.

The agency is considering a lower limit of 2,200 N for the WorldSID-50M resultant sacroiliac force, which corresponds to a 10 percent risk of AIS 2+ injury for a 67-year-old occupant. As is illustrated in chart W8 of appendix XV, none of the vehicles tested in the agency's side pole validation tests had resultant sacroiliac readings that were lower than this limit; however, four of the six side MDB tests did.[188] Even though none of the pole validation tests would achieve full points for this criterion, forces ranged from 2.2 kN to 3.6 kN. Therefore, the agency believes that this limit is appropriate since: (1) the experimental data set showed injury for several PMHS at even lower force levels, (2) it is achievable by the fleet and, (3) in combination with the upper limit, it will serve to differentiate between vehicles.

Upper Limit. For the WorldSID-50M, the agency is considering an upper limit for pubic force of 1,932 N, which is equivalent to a 25 percent risk of AIS 2+ injury. The agency believes

[187] Petitjean, A., Trosseille, X., Praxl, N., Hynd, D., Irwin, A., "Injury Risk Curves for the WorldSID 50th Male Dummy," Stapp Car Crash Journal, 56: 323-347, 2012.

[188] Sacroiliac force data for one occupant in a side pole validation crash test was lost due to instrumentation error.

that this limit is appropriate and achievable, as all of the vehicles from the side MDB and side pole validation tests recorded lower pubic force readings. Furthermore, the PMHS data set showed numerous instances of injury at this risk level.

The agency is considering an upper limit for resultant sacroiliac force of 3,720 N for the WorldSID-50M, which corresponds to 50 percent risk of AIS 2+ injury. By setting a higher upper risk threshold for the resultant sacroiliac force, similar to the upper risk of the shoulder force, the agency can drive improved protection without masking performance for this region. Resultant sacroiliac forces recorded for all side validation test vehicles were less than this limit, thus suggesting that it is attainable.[189] Furthermore, due to the large range in resultant sacroiliac forces seen in the agency's pole testing (forces from 2.2 kN to 3.6 kN), the agency believes that setting an upper limit of 50 percent risk is beneficial to maximize fleet differentiation.

4. SID-IIs Upper and Lower Injury Limit Discussion

The upper and lower injury limits that the agency plans to use for the SID-IIs ATD were determined by considering the available injury risk functions, validation test data, and the recent NCAP fleet data for the current program in an attempt to maximize fleet differentiation to spur safety improvements. NHTSA is requesting comment on these upper and lower injury limits, as well as the underlying risk curves presented below.

HEAD (HIC15 and BrIC)

Consistent with the THOR-50M and WorldSID-50M ATD, the agency will choose from the worse of two injuries measured by the dummy to assign points estimating the head injury risk to that occupant. As shown in the list of SID-IIs risk curves in appendix V, and as detailed earlier

[189] Ibid.

in the injury criterion section of this notice for the side impact program, an AIS 3+ HIC_{15} assessment and an AIS 4+ assessment of BrIC responses are planned.

Lower Limit. For the SID-IIs, the agency is considering setting a lower limit for HIC_{15} of 500. This equates to a 4.7 percent risk of an AIS 3+ skull fracture using the risk curve presented in appendix V. Even though all of the agency's validation tests would achieve this performance limit, as stated previously, the agency does not want to arbitrarily set a lower bound for the HIC_{15} injury criterion that is less than what is necessary and feasible, since differentiation between vehicles below what could already be considered to be a low threshold would not be very meaningful. Furthermore, as mentioned in the WorldSID-50M head upper limits discussion, NHTSA is retaining both injury criteria for the side impact dummies' heads even though validation testing shows that HIC_{15} will likely have minimal effect on the ratings generated.

The agency is considering setting a lower limit for BrIC of 0.65 for the SID-IIs dummy, which equates to a five percent risk of AIS 4+ injury according to the formula presented in appendix V. This harmonizes the SID-IIs BrIC lower limit with that of the WorldSID-50M. As seen in chart S2 of appendix XV, BrIC values reported in the agency's validation testing ranged from 0.36 to 1.25. Two of the vehicles achieve this level of performance. The agency believes this limit would provide the desired differentiation in fleet performance, be attainable, and ensure that appropriate head protection is provided.

Upper Limit. The agency is considering setting a SID-IIs upper limit of HIC_{15} of 700. According to the AIS 3+ risk curve presented in appendix V, the injury risk associated with a HIC_{15} of 700 is 11.2 percent.

The agency is considering a SID-IIs upper limit for BrIC of 0.85, or a 25 percent risk of AIS 4+ injury according to the formula presented in appendix V. Only one of the validation test vehicles would not meet this performance limit. The agency believes that an upper limit of 25 percent risk will drive the appropriate level of improvements to side air bag coverage for the rear passenger as opposed to the 50 percent risk proposed in frontal. It is also consistent with the planned upper limits for BrIC for the WorldSID-50M ATD.

CHEST (Maximum Thoracic Rib Deflection)

As previously discussed in detail in the injury criteria section for the SID-IIs, the agency is considering multiple risk curves from which to base lower and upper performance limits for SID-IIs maximum thoracic rib deflection. The AIS 3+ thoracic rib deflection injury risk function included in the December 2015 RFC notice and Irwin et al.'s AIS 3+ thoracic rib deflection injury risk function are both shown in appendix V. Comments are requested on the advantages of either risk function and its associated limits.

Lower Limit. As NHTSA is still considering two risk functions for this criterion, two sets of lower limits have been generated for an injury risk level of five percent. For the injury risk function published in the December 2015 RFC notice, the agency would consider a maximum thoracic rib deflection lower limit for the SID-IIs of 19 mm, as this equates to five percent risk of injury. Five percent risk of injury when considering Irwin et al.'s AIS 3+ risk function equates to 31 mm. For the lower performance limit planned for NHTSA's risk curve, four of the six validation test vehicles and 38 percent of NCAP's MY 2014-2016 fleet would fall below this performance limit.[190] When considering the performance limit planned for the Irwin et al. risk curve, five of the six validation test vehicles and 67 percent of NCAP's current fleet would fall below.[191] Although a large portion of the current fleet is already meeting this

[190] For MY 2014-2016 side MDB NCAP tests in the current program.
[191] Ibid.

performance threshold, the agency does not believe it is appropriate to lower the percent risk of injury any further, as this would not generate meaningful improvements in vehicle safety.

Upper Limit. As with the lower limit, the agency is considering two upper thresholds for SID-IIs thoracic rib deflection. Per the risk curves presented in appendix V, 25 percent risk of AIS 3+ thoracic injury for NHTSA's and Irwin et al.'s risk curves equates to 31 mm and 39 mm, respectively. If using the upper thoracic rib deflection performance limit for NHTSA's risk curve, five of the six validation test vehicles and 66 percent of the current NCAP fleet meet this performance limit.[192] All validation test vehicles fall below the performance limit for Irwin et al.'s risk curve, as does 94 percent of NCAP's current fleet.[193]

ABDOMEN (Maximum Abdomen Deflection)

Lower Limit. The agency is considering excluding a lower limit for maximum abdomen rib deflection for the reasons discussed in the SID-IIs injury criteria section of this notice. Because of the high severity level of the current injury risk curve available for this injury criterion, the agency believes a lower performance target for abdomen response is not appropriate for the SID-IIs at this time.

Upper Limit. Despite the limitations noted above, the agency is considering an upper performance limit for the SID-IIs abdomen deflection to protect against severe abdomen injuries. The current limit used to assign a footnote in NCAP's current side crash program for the SID-IIs abdominal rib deflection is 45 mm, which equates to five percent risk of AIS 4+ abdominal injury. Because the risk curve used to generate this percent risk of injury is of a higher AIS level than the other body regions (other than BrIC), and an AIS 3+ risk curve has not been generated at this time, the agency believes it is acceptable to set the upper limit for this criterion at a value

[192] Ibid.
[193] Ibid.

that is lower than five percent risk of injury. Therefore, the agency is considering setting the upper performance limit at 80 percent of the current limit, or 36 mm. Of the six validation tests, five of the vehicles would achieve this performance, and reported deflections ranged from 3 mm to 39 mm. The MY 2014-2016 side MDB NCAP tests revealed that 12 percent of vehicles would have exceeded this threshold.[194] The agency believes this limit is attainable and the need to encourage improved protection for the abdomen still exists.

LOWER SPINE (Resultant Acceleration)

Lower Limit. The agency is not considering the SID-IIs lower spine resultant acceleration lower limit because the agency is still not aware of the existence of a valid risk curve.

Upper Limit. The agency is considering setting the SID-IIs lower spine resultant acceleration upper limit at 66 G. This equates to 80 percent of the IARV currently included in FMVSS No. 214 for the SID-IIs ATD. For this criterion, the agency believes there is merit to setting the upper limit to be less than the compliance limit to incentivize vehicle manufacturers to make additional safety improvements. Five of the six validation test vehicles would meet this performance and the range of resultant acceleration was from 22 G to 72 G. When reviewing the recent MY 2014-2016 side NCAP MDB test data, 82 percent of vehicles would meet this performance limit, thus suggesting that this limit is attainable.[195]

PELVIS (Combined Pelvic Force)

As mentioned earlier in this notice in the injury criteria section for the SID-IIs, the agency plans to assess combined acetabular and iliac force pelvic injuries at the AIS 2+ severity level.

[194] Ibid.
[195] Ibid.

Lower Limit. The agency is considering setting the SID-IIs combined pelvic force lower limit at 3,575 N. This equates to a five percent risk of injury given the AIS 2+ formula in appendix V. As shown in chart S6 of appendix XV, only one of the agency's validation tests would not meet this performance limit. However, when looking at data from the current NCAP fleet, 24 percent of the vehicles would not achieve this performance limit.[196]

Upper Limit. The agency is considering setting the upper combined pelvis force limit for the SID-IIs at the FMVSS No. 214 regulatory limit of 5,525 N. This equates to a 25 percent chance of injury given the AIS 2+ formula listed in appendix V. Since the agency has been using this limit for current regulation and the current NCAP,[197] the agency would like to continue the use of this limit for this NCAP upgrade. The agency is not setting the upper limit at 80 percent of the IARV, as was done for the upper limit for lower spine acceleration, because, similar to that mentioned for the WorldSID-50M, the agency would like to encourage vehicle manufacturers to direct loading to the more robust body regions, such as the pelvis, over more vulnerable regions, like the thorax. Since, as was indicated earlier, the agency is including a lower spine acceleration injury criterion for the SID-IIs because it is shown to be indicative of overall loading to the thorax, the agency believes there is merit to making the upper limit for that criterion more stringent compared to that for the pelvis.

A summary of the upper and lower limits planned for both the WorldSID-50M and the SID-IIs is presented in table 3 below.

Table 3 – Summary of upper and lower injury limits for use with the WorldSID-50M and the SID-IIs linear scale approach.

	WorldSID-50M	SID-Iis

[196] Ibid.
[197] Two percent of the current NCAP fleet exceeded this upper limit.

Body Region	Injury Criteria	Lower Limit Value (Full credit, 1 point)	Upper Limit Value (No credit, 0 points)	Lower Limit Value (Full credit, 1 point)	Upper Limit Value (No credit, 0 points)
Head	**HIC_{15}**	500	700	500	700
	BrIC	0.65	0.85	0.65	0.85
Shoulder	**Peak Force**	NA	2,500 N	NA	NA
Chest	**Peak Chest Deflection**	27 mm	50 mm	19 mm (NHTSA)/ 31 mm (Alternative)	31 mm (NHTSA)/ 39 mm (Alternative)
Abdomen	**Peak Chest Deflection**	NA	47 mm	NA	36 mm
Lower Spine	**Peak Resultant Acceleration**	NA	NA	NA	66 G
Pelvis	**Pubic Force**	1,330 N	1,932 N	NA	NA
	Peak Resultant Sacroiliac Force	2,200 N	3,720 N	NA	NA
	Acetabulum Iliac Force	NA	NA	3,575 N	5,525 N

5. Weighting the Injuries Assessed for Each Occupant

In addition to determining the linear scale limits, the agency is planning on weighting the various body regions for each dummy. Weights chosen for the body regions assessed for each occupant should not only take into account injuries seen in real-world data, but should also incentivize vehicle manufacturers to improve vehicle safety as a whole. As a result, the weights assigned to various body regions may not reflect the same proportions with which injuries occur in the fleet.

Once data is collected from the occupants in each NCAP frontal, side MDB and side pole test, each injury being considered for inclusion into the rating will be converted to a value using the linear scale approach discussed above. Each converted injury reading, which will be equal to or between 0 and 1, will be weighted and summed for each occupant. Tables 5 through 9 show weighting proportions of all body regions planned for use in this NCAP upgrade by occupant location as discussed previously and illustrated in figure 2.

Table 4 –THOR-50M Planned Body Region Weighting Proportions

Head	Neck	Chest	Abdomen	Lower Body	
				KTH	Lower Leg
25 percent	25 percent	25 percent	Upper Limit	12.5 percent	12.5 percent

Table 5 – Right Front Seat HIII-5F Planned Body Region Weighting Proportions

Head	Neck	Chest	KTH
33.3 percent	33.3 percent	33.3 percent	Upper Limit

Table 6 – Rear Seat HIII-5F Planned Body Region Weighting Proportions

Head	Chest	Abdomen (submarining assessment)
50 percent with head contact	100 percent without head contact, 50 percent with head contact	Upper Limit

Table 7 – WorldSID-50M Planned Body Region Weighting Proportions

Head	Shoulder	Chest	Abdomen	Pelvis
33.3 percent	Upper Limit	33.3 percent	Upper Limit	33.3 percent

Table 8 – SID-IIs Planned Body Region Weighting Proportions

Head	Chest	Abdomen	Lower Spine	Pelvis
33.3 percent	33.3 percent	Upper Limit	Upper Limit	33.3 percent

6. Assignment of Stars

In the new rating system, the agency plans to use a singular crashworthiness score. A potential 5-star rating scale that relates the crashworthiness total point score is shown in table 9.

Table 9 – Crashworthiness 5-Star Rating Scale (100 Point Scale)

Lower Total Point Score (Greater than or equal to)	Crashworthiness Stars	Upper Total Point Score (Less than)
0	No stars	5

5	½	10
10	1	20
20	1-½	30
30	2	40
40	2-½	50
50	3	60
60	3-½	70
70	4	80
80	4-½	90
90	5	100

Based on the above crashworthiness 5-star rating scale, table 10 displays the crashworthiness point score total with the corresponding star rating for the six vehicles conducted by the agency in its validation testing.

Table 10 – Validation Test Vehicle Performance (Based on New Crashworthiness Rating System)

Validation Test Vehicles	**Total CW Score (Points)**	**Total CW Score (Stars)**
2016 Chevrolet Malibu Limited	52.7	3
2016 Nissan Rogue	45.5	2-½
2016 Honda Fit	42.2	2-½
2015 Toyota Sienna	44.8	2-½
2016 Chevrolet Tahoe	56.7	3
2016 Ford F-150	53.7	3

The highest crashworthiness total point score in the validation test series – 56.7 total crashworthiness points scored by the 2016 Chevrolet Tahoe – earns a 3-star crashworthiness rating. This relatively modest rating scale is designed to balance the difference in performance between present-day vehicles with the future new models, allowing room for further vehicle safety improvements and ultimately higher star ratings. When examining the components of the pilot vehicle crashworthiness assessments, scores of "zero" in many of the sub-assessments (detailed in the spreadsheet mentioned above) brought the overall scores down. For each vehicle in the validation testing (including the Chevrolet Tahoe), there were at least two sub-assessments that received scores of zero. This was expected because this NCAP upgrade includes, among other things, new test conditions and more advanced ATDs. The vehicles in the validation test series were likely not designed to meet the new protocols.

The crashworthiness star rating scale also allows for vehicles that perform worse than those in the validation test series. No vehicles in that test series were rated lower than 2-½ crashworthiness stars. The lowest crashworthiness total point score was 42.2 points, scored by the 2016 Honda Fit. This does not necessarily indicate that the new crashworthiness rating scale is too generous. The six vehicle models in the validation test series were chosen based on good past performance. Five of the six vehicles received an "ACCEPTABLE" score or better by IIHS. In addition, they all received 4-star or 5-star ratings under the current NCAP. Furthermore, they all comply with the NHTSA's latest crashworthiness standard, FMVSS No. 226, "Ejection mitigation." Since the vehicles tested in the validation test series are considered good performers, the agency adjusted the crashworthiness rating scale with the expectation that there are other vehicles that will perform more poorly.

Furthermore, to ensure a minimum amount of consideration is given to NCAP-related safety assessments, a "no star" rating is given when the crashworthiness point total score is less than 5. This reflects the idea that NCAP ratings are designed to ensure future vehicle designs would achieve minimum performance standards.

B. Crash Avoidance Sub-Rating System

As mentioned in the December 2015 RFC notice, the agency intends to establish a new rating for crash avoidance systems. To continue the accepted method of communicating information to consumers, a 5-star safety rating format is preferred. However, as noted above, the agency has not conducted consumer testing on this assumption, which may be done in support of the future rulemaking. If that testing shows consumers prefer another form of rating for crash avoidance (e.g., a listing of the included technologies), the agency would update the program in conjunction with revising the label. Also explained in the December 2015 RFC notice, the agency intends to include assessments of 11 crash avoidance systems as part of the new rating system for the NCAP upgrade – nine (9) technologies in the crash avoidance rating category and two (2) crash avoidance technologies in the pedestrian rating category that is described in the next section. In the April 5, 2013, RFC notice and the December 2015 RFC notice, NHTSA noted "there are four prerequisites for considering an area for adoption as a new NCAP enhancement." First, a safety need must be known or be capable of being estimated based on what is known. Second, vehicle and equipment designs must exist or at least be anticipated in prototype designs that are capable of mitigating the safety need. Third, a safety benefit must be estimated, based on the anticipated performance of the existing or prototype design. Finally, it must be feasible to develop a performance-based objective test procedure to measure the ability of the vehicle technology to mitigate the safety issue.

The agency is requesting comment on the rating methodology presented in this notice for crash avoidance systems, which shows a modest refinement of the ranking criterion since the December 2015 notice. The rating would be applied to each individual vehicle, rather than to entire trim lines or models, to provide the most accurate and detailed safety information to consumers. The rating framework would resemble the point system described in the December 2015 notice; however, the safety improvement potential of each technology would be added together and then converted to a percentage value rather than a raw number of points. The use of percentage values for individual crash avoidance systems promotes consistency in applying the rating methodology throughout NCAP updates as new crash avoidance technologies are added or existing crash avoidance technologies are removed from the rating. The primary basis of the estimate for each individual system is the proportion of its individual safety improvement potential divided by the sum of all the safety improvement potential for all of the systems in the crash avoidance rating program. However, slight adjustments are necessary to more appropriately give context to the underlying crash conditions. In a rigid, unadjusted application of a simple proportional methodology, the rollover resistance scoring element would garner a substantially reduced percentage, yet the historic datastream indicates approximately one-third of passenger vehicle occupants are killed in rollover crashes each year; therefore, the agency believes 18 percent is more representative. Similarly, a rigid, unadjusted application of a simple proportional methodology would show headlighting systems overrepresented in the cumulative safety improvement potential; therefore, the agency believes 20 percent is more representative. A technology's potential safety improvement is based on the assumed effectiveness of that technology in preventing crashes within a given technology's target population.

Based on the agency's current understanding, the effectiveness of the nine crash avoidance systems are generally assumed to be mutually exclusive. However it is possible that multiple systems may address the same target population. For example, both the rearview video system technology currently in NCAP and the rear automatic braking system technology being added to NCAP address the same target population. In estimating the safety improvement potential of individual systems, the agency is aware of possible accounting overlap and therefore attempts to segregate the estimated system effectiveness of different systems. Therefore, effectiveness apportioned to rear automatic braking systems is discounted by the effectiveness apportioned to rearview video systems.

Another modest refinement was made to the distinct rollover resistance percentages to correlate with the results of the static stability factor measurement.[198] Vehicles with a SSF greater than or equal to 1.45 would earn 18 percent for rollover resistance; a SSF greater than or equal to 1.18 and less than 1.45 would earn 12 percent; a SSF greater than or equal to 1.08 and less than 1.18 would earn six (6) percent; a SSF greater than or equal to 1.02 and less than 1.08 would earn 4 percent; a SSF less than 1.02 would earn 2 percent. Any vehicle that results in a 'tip-up' during execution of the fishhook test[199] would score zero percent for the rollover resistance, regardless of the SSF measurement.

Table 11 summarizes the maximum scoring value for each crash avoidance system. A minimum scoring value threshold of five (5) percent was established for any crash avoidance system included in the NCAP rating, thereby reflecting the potential contribution of reducing both fatalities and injuries. Although the scoring values track towards the proportion of fatalities, the 5 percent minimum threshold reflects consideration of injuries. Adjustments to the scoring value percentages were made based on existing or previously published effectiveness estimate analyses. Appendix XIV contains an annotated table of how the crash avoidance system maximum score values were determined. The agency requests comment on the revised scoring value percentages.

Table 11 – Crash Avoidance System Maximum Score Values

Crash Avoidance System	Safety Improvement Potential: Fatalities	Safety Improvement Potential: Injuries	Revised Scoring Values *Percentage*
FCW	35	1,260	10 percent

[198] Laboratory Test Procedure For Rollover Stability Measurement For NCAP, Static Stability Factor (SSF) Measurement, available at http://www.safercar.gov/staticfiles/safercar/NCAP/SSF_Test_Procedure-March2013.pdf.
[199] Laboratory Test Procedure for Dynamic Rollover, The Fishhook Maneuver Test Procedure, available at http://www.safercar.gov/staticfiles/safercar/NCAP/NCAP_Fishhook_Test_March_2013.pdf.

CIB	40	640	12 percent
DBS	25	2,100	8 percent
Lower beam headlighting distance	240	10,000	20 percent
Semi-automatic headlamp beam switching	60	2,000	10 percent
Amber rear turn signal lamps	0	882	5 percent
LDW	131	3,280	12 percent
Rollover Resistance	101	344	18 percent
Blind Spot Detection	5	1,332	5 percent
Total	637	21,838	100 percent

Consistent with the December 2015 RFC notice, the crash avoidance star rating scale would be a simple conversion of one star for every 20 percentage credits accumulated as shown in table 12. The crash avoidance scale does not utilize half star increments.

Table 12 – Crash Avoidance Rating Scale

CA Percentage Total	CA Rating
1-19 percent	1 star
20-39 percent	2 stars
40-59 percent	3 stars
60-79 percent	4 stars
80-100 percent	5 stars

For demonstration purposes, a scoring exercise was conducted to generate a representative crash avoidance score and star rating for each of the six vehicles in the validation test series. Note that these stars are derived from the crash avoidance rating scale percentage estimates. Since every vehicle contains headlighting systems and is currently evaluated for rollover resistance performance, the likely minimum crash avoidance rating would be 1 star. It is highly unlikely that a vehicle would score zero points toward the crash avoidance rating; a zero score would indicate a vehicle with an extremely poor-performing headlighting system and that had a tip-up recorded during the NCAP fishhook test (a rollover resistance scoring element). On the other end of the rating spectrum, to earn a 5-star crash avoidance rating, the CIB and DBS systems must perform at the NCAP test procedure speeds, which is challenging for many vehicles currently on the market. Finally, scoring criteria were established based on the safety improvement potential of crash avoidance systems that could be added to a vehicle, independent of what is currently available in the fleet.

For this exercise, the agency crash avoidance testing results were not used, nor were self-generated assessments obtained from the vehicle manufacturer. Instead, scoring was estimated using the following assumptions that considered the various trim level options as reported by the manufacturers:

- For FCW, Semiautomatic Headlamp Beam Switching, Amber Rear Turn Signal Lamps, LDW, and BSD systems, if a vehicle was equipped with one of these systems, then it was considered to have successfully passed the NCAP test procedure and received full performance scores for that respective system.
- For CIB and DBS systems, if a vehicle was equipped with one of these systems and manufacturer literature (i.e., owner manual or website specification) indicated capability to pass the NCAP test procedure,[200] then it received full performance scores for that respective system. If a vehicle was equipped with one of these systems and manufacturer literature only indicated capability to achieve the AEB MOU performance level,[201] it received a score of zero for that respective system.

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[200] NCAP does not require any manufacturer to provide crash avoidance information of any kind, whether in owner manuals, websites, or other information media. For the purposes of this exercise, NHTSA obtained information relevant to these CIB and DBS systems based on publicly available published or advertised capabilities.
[201] See the Auto Industry Commitment to IIHS and NHTSA on Automatic Emergency Braking available at http://www.nhtsa.gov/staticfiles/nvs/pdf/AEB_FactSheet_031616.pdf. The maximum AEB Memorandum of Understanding (MOU) system performance is structured to achieve only a subset of the current NCAP Recommended Advanced Technology Features AEB requirements. The maximum NCAP AEB system performance exceeds the maximum AEB MOU performance. Success in any AEB MOU test would not earn credit toward the NCAP Crash Avoidance rating.

• For rollover resistance, the vehicle received a scaled score based on the current rollover star rating obtained via www.safercar.gov. In this exercise, the vehicle models analyzed were rated either 3- or 4-stars based on known NHTSA rollover test results. If a vehicle was assigned 4-stars for rollover under the current NCAP rating, then it scored 12 percent; if a vehicle was assigned 3-stars for rollover under the current NCAP rating, then it scored 6 percent.

• For Lower Beam Headlighting systems, the vehicle received a scaled score based on reported lamp type. For the purposes of this exercise, a vehicle with halogen headlamps scored 10 percent and a vehicle with LED headlamps scored 12 percent.

Figure 4 summarizes the results of this analytical exercise by vehicle model and shows that one vehicle model may earn multiple, different ratings due to different trim levels. For example, the Tahoe scored 1-, 2-, or 3-stars depending on the trim level and optional crash avoidance equipment. If a technology is optional for a particular trim level and a consumer purchases that vehicle with the option, the crash avoidance rating would reflect the as-purchased vehicle configuration. The shaded bar graphically represents the range of the possible ratings. The arrow indicates the rating that a specific vehicle trim level and configuration earned. In this way, NCAP would quickly communicate to a consumer the rating of the specific vehicle configuration being considered for purchase as well as the range of ratings available within the same model through different equipment options.

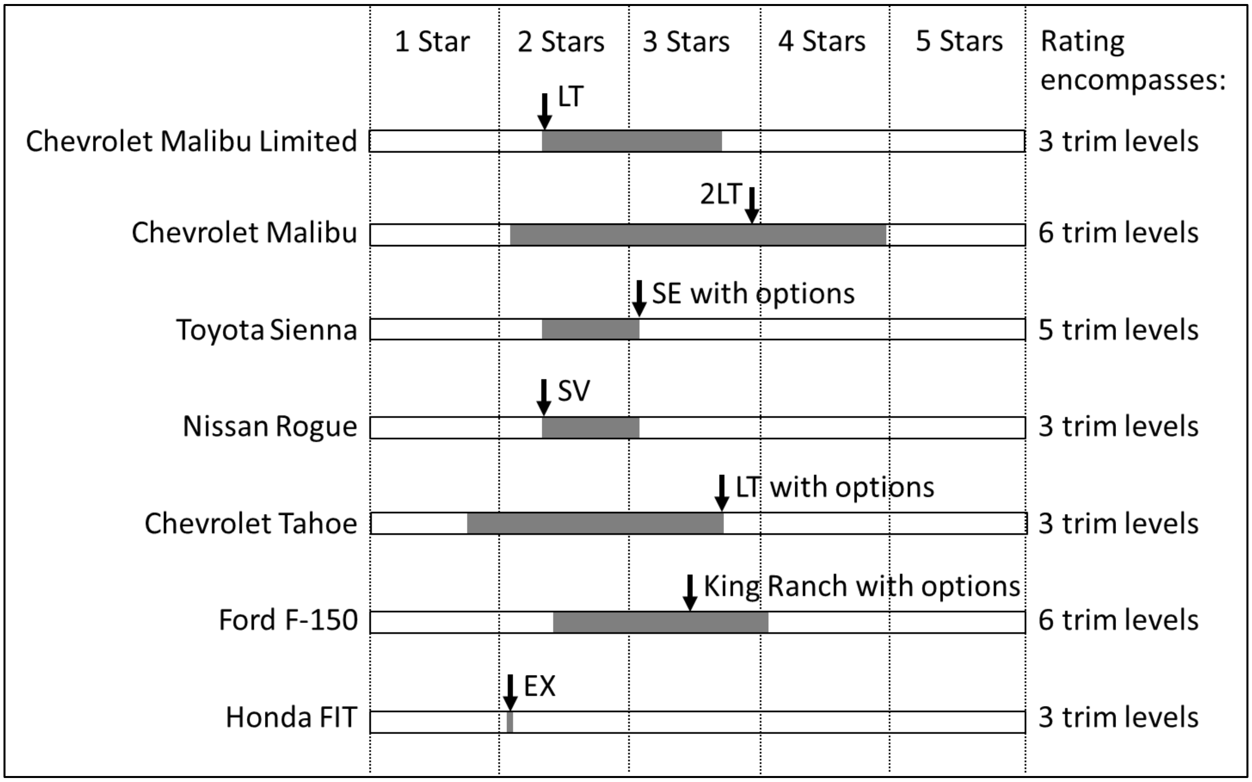

Figure 4 – Crash Avoidance Star Rating For NCAP Scoring Exercise[202]

This figure shows how the crash avoidance sub-rating system could vary from 1- to 4-stars among this sample of vehicles based on trim level and vehicle equipment options purchased. A 4-star rating was achieved by two vehicles; the 2016 Chevrolet Malibu Premier model with the Driver Confidence Package and the Diver Confidence Package II; the 2016 Ford F-150 Platinum model with Equipment Group 701A or the F-150 Limited model. As a general

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[202] For this exercise, the 2016 Chevrolet Malibu Limited was equipped with halogen headlamps, amber rear turn signal lamps, and optionally equipped with BSD, FCW and LDW; the 2016 Chevrolet Malibu was equipped with halogen headlamps, and standard or optionally equipped with BSD, FCW, CIB, DBS, semi-automatic headlamp beam switching and LDW; the 2016 Toyota Sienna was equipped with halogen headlamps and amber rear turn signal lamps, and standard or optionally equipped with BSD and semi-automatic headlamp beam switching; the 2016 Nissan Rogue was equipped with halogen headlamps and amber rear turn signal lamps, and standard or optionally equipped with LED headlamps, FCW, and BSD; the2016 Chevrolet Tahoe was equipped with halogen or HID headlamps, and standard or optionally equipped with BSD, FCW, semi-automatic headlamp beam switching and LDW; the 2016 Ford F-150 was equipped with halogen or LED headlamps, and standard or optionally equipped with BSD, FCW, CIB, DBS, semi-automatic headlamp beam switching and LDW; the 2016 Honda FIT was equipped with halogen headlamps.

matter, the vehicles that scored higher tended to be the more expensive, higher trim levels.[203] As stated above, the agency assumed full performance scoring for several of the various technologies without conducting the NCAP test. Thus, the four-star rating shown in figure 4 may not be reproduced after examination of actual performance.

As consumers are offered vehicles equipped with more crash avoidance systems and are educated on the safety improvement potential of these crash avoidance systems, the agency expects that a 5-star crash avoidance rating would be achievable in the future. This crash avoidance rating system would accommodate current systems on production vehicles as well as encourage further development on evolving systems. Moreover, this rating system would encourage manufacturers to add crash avoidance technologies to more of their trim levels, thereby potentially earning higher rating ranges across all trim levels. The agency notes that each trim level was lacking at least one system necessary to attain a 5-star crash avoidance rating. For example, Ford offers various equipment combinations for the F-150 that enable two of the six trim levels to attain a 4-star crash avoidance rating. The agency also notes that the 2015 Honda Fit was equipped with two crash avoidance systems that combined to score a 2-star crash avoidance rating for all of its trim levels.

C. Pedestrian Protection Sub-Rating System

As mentioned previously, NHTSA intends to rate vehicles using results from the four crashworthiness pedestrian tests (two headform, one upper legform, and one lower legform) and system performance tests of two advanced crash avoidance technologies (PAEB and rear

[203] Since NCAP is focused on safety performance of available crash avoidance systems, vehicle cost and sales volume (popularity) are not relevant parameters in the NCAP crash avoidance evaluation. Cost is clearly indicated on the Monroney label, a copy of which is often available to consumers on the manufacturer website. The sales volume, which can be readily obtained via an internet search, is not a factor as to which active safety systems are designated as an NCAP Recommended Advanced Technology Feature.

automatic braking) that have the potential to avoid or mitigate crashes that involve a pedestrian and improve pedestrian safety. From a consumer perspective, the agency believes that it is beneficial to aggregate the scores of PAEB and rear automatic braking systems with a vehicle's crashworthiness pedestrian protection scores so that a separate, single pedestrian protection score could be clearly distinguished from the other two rating categories (crashworthiness and crash avoidance). Consumers could then make informed purchasing decisions about whether to purchase vehicles that are equipped with these pedestrian safety related features and technologies. As noted, the agency may conduct consumer testing on these assumptions as part of a rulemaking to update the Monroney label. The results of this potential research may change the way the agency presents pedestrian information on the new Monroney label.

1. Pedestrian Crashworthiness Rating

NHTSA plans to use essentially the same methods as employed by Euro NCAP to assess vehicle crashworthiness for pedestrian safety. Using these methods, an overall assessment for vehicle crashworthiness performance is accomplished through the combination of results from multiple tests. These test series include the following: approximately 165 assessments are performed on the hood, windshield, and A-pillars via headform tests; 15 assessments are performed on the bumper area with the Flex-PLI; and 15 assessments are performed on the forward edge of the front-end with the upper legform.

The multitude of assessments allows the components of the pedestrian safety score to be pin-pointed to highly specific points on the vehicle. As a result, pedestrian scoring is generally more tolerant of a low score in any particular assessment (for a particular grid point) than the crashworthiness rating, where one elevated dummy measurement can result in a steep reduction in the overall crashworthiness rating. For the pedestrian crashworthiness rating, a single score of a single grid point does not typically reflect the overall rating.

Apportioning of assessments for headform, upper legform, and Flex-PLI tests. In Euro NCAP, the overall pedestrian crashworthiness rating combines the headform tests, Flex-PLI tests, and upper legform tests as follows: 66.67 percent is apportioned to test results with the headforms, 16.67 percent to the Flex-PLI, and 16.67 percent to the upper legform. For this NCAP upgrade, NHTSA plans to apportion 37.5 percent to the headform, 37.5 percent to the Flex PLI, and 25 percent to the upper legform. The agency requests comment on these apportionments. [204]

NHTSA's apportioning is influenced by agency study of real-world pedestrian injuries in the U.S.[205] In this study the agency determined how the areas of the vehicle monitored by the three component tests contribute to pedestrian injuries in the real world. Among serious injury cases (MAIS 3 or worse, including fatalities), the surface areas on the vehicle monitored by the headform test and the Flex-PLI test are each associated with 37.5 percent of all injuries caused by contacts with the combined area monitored by all three NCAP component tests. The area monitored by the upper legform test is associated with the remaining 25 percent. The agency is considering using these percentages in NCAP as they are consistent with the overall target population of U.S. pedestrian injuries suffered in collisions up to and including 40 km/h.

Effect on range of scores. The agency also considered the possibility that 37.5 percent/37.5 percent/25 percent apportioning could have a detrimental effect on pedestrian safety. In reviewing recent Euro NCAP data, most vehicles attain full points on the bumper

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[204] See "PedestrianProtectionComputations.xlsm" in Docket No. NHTSA-2015-0119.
[205] See "Apportionment of US Pedestrian Injuries by NCAP Test Procedure" in NHTSA-2015-0119, available at http://www.regulations.gov/docket?D=NHTSA-2015-0119.

assessment via Flex-PLI testing. It may appear that increasing this allotment from 16.67 percent to 37.5 percent could produce a narrower range of overall pedestrian safety scores, thus making it more difficult to discriminate bumper safety among vehicles. However, the U.S. does not currently have any requirements for vehicle crashworthiness pedestrian protection and, upon examination of Euro NCAP data and NHTSA's own test results, there are key differences in the U.S. vs. European vehicle market. These differences in both the regulation and the vehicle fleets should widen the range of scores obtained by NHTSA, not narrow them, if 37.5 percent/37.5 percent/25 percent apportioning is used in this NCAP upgrade.

There are many vehicles that are unique to the U.S. market, meaning they do not have European variants. Included among U.S.-only vehicles are those with high ground clearance, such as pickup trucks. Those vehicles will be assessed under the NCAP upgrade, but it is not likely that this class of vehicles would achieve a full score on the bumper assessment.

Other U.S. vehicles have European variants that have attained full points on the Euro NCAP bumper rating. However, the European variants typically have front-ends that differ slightly in construction, due to regulatory differences between the U.S. and Europe. The European variants contain front-end components designed specifically for pedestrian safety. These include the grille, energy absorber (beneath the fascia), headlight brackets, and lower valence.

Origin of Euro NCAP apportioning. Euro NCAP assessments (version V5 and earlier) followed the original European Enhanced Vehicle-safety Committee (EEVC) procedure for hood/windshield markups that was intended for regulatory purposes in which the child and adult headform test areas were split at WAD1500. This created two test areas of near equal size: WAD1000 to WAD1500 for the child headform, and WAD1500 to WAD2100 for the adult headform. The procedure further split each test area into test zones of equal size: six zones for the child headform and six zones for the adult headform. A test was performed at the "worst case" point (as determined by the test laboratory) of each test zone for each headform. This amounted to six adult headform tests and six child headform tests.

The front end of the vehicle was also divided similarly: six test points along the width of the hood leading edge for the upper legform and six test points along the width of the bumper for the lower legform. Since the legform tests were performed along the front end at the same height, only three tests were run by reasoning that symmetry would render the same result right vs. left. This amounted to three upper legform tests and three lower legform tests.

Each test was awarded a score ranging from zero to two points, giving maximum totals of 24 points for the headform tests, six points for the three upper legform tests, and six points for the lower legform tests. This 24/6/6 apportioning (or 66.67 percent/ 16.67 percent/16.67 percent) is still applied in the latest Euro NCAP rating procedure even though the number of assessment points has changed; it now varies depending on the size of the vehicle.

Scoring of individual component tests. For each individual NCAP component test, upper and lower performance limits are used to compute a test score for the grid point under assessment. Full points are awarded for performance under the lower limit, no points are given for performance above the upper limit, and partial points are given in between the upper and lower limits using a linear sliding scale. This applies to all tests, including adult headform tests, child headform tests, Flex-PLI tests, and upper legform tests.

The agency's basis for setting the performance limits is discussed in greater detail below. In instances where the agency's performance limits differ from those of Euro NCAP, a full discussion and justification is provided within a NHTSA report contained in the docket.[206]

Upper performance limits. The agency's approach in setting the upper performance limits (i.e., the least stringent) is to set them at the PASS/FAIL limit of a corresponding regulatory test, if one exists. This includes Flex-PLI limits for tibia bending (340 Nm) and collateral ligament stretch (22 mm) and the upper limit for headform tests (HIC>1,700), all of which have been established for UNECE Regulation No. 127.[207] No points are awarded when these limits are exceeded.

Lower performance limits. NHTSA plans to set lower limits sufficiently low as to drive safety to the fullest and to provide the best discrimination among vehicles. Doing so would reward the best performers with the highest ratings. The agency examined injury risk curves to aid in this determination by making sure that risk remains on a linear scale decrease from values just above the limit. The agency also considered vehicle performance to assure that the lower limits are actually being achieved.

Qualifiers. The agency plans to treat performance measures for the elongation of the Flex-PLI's anterior and posterior cruciate ligaments (ACL and PCL) as "qualifiers" where only a single performance limit applies. Points are not awarded based on these measures. Instead,

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[206] "Technical Modifications to: Euro NCAP Assessment Protocol for Pedestrian Protection, Version 8.1 for use in the New Car Assessment Program, August 2016," in NHTSA-2015-0119, available at http://www.regulations.gov/docket?D=NHTSA-2015-0119.

[207] Regulation No. 127, pedestrian safety, was enacted in January 2013 through the United Nations' Economic Commission for Europe, World Forum for the Harmonization of Vehicle Regulations (WP.29) for all nations under the 1958 Agreement. It mirrors Global Technical Regulation (GTR) No. 9, which serves as a template for domestic regulations of WP.29 contracting parties subscribing to the 1998 agreement (including the U.S.). As a signatory to WP.29 representing the U.S., NHTSA voted "yes" for the GTR in November 2008. Reg. No. 127 was subsequently implemented as a full UNECE regulation in January 2013 by subscribers of the 1958 agreement. The U.S. is not a party to the 1958 agreement.

qualifiers act as safeguards against unusual performance, and they only factor into the score when their performance limits are exceeded, in which case points are deducted.

Modifications to the Euro NCAP Assessment Protocol, V8.1. The modifications described below pertain only to the Part 1: Pedestrian Impact Assessment of the Euro NCAP assessment protocol for pedestrian protection. Part 2, Pedestrian AEB Assessment, does not apply to this program upgrade. The agency's PAEB assessment will be carried out using an entirely different set of procedures which are described in the next section of this notice.

Performance limits – headform. Under the Euro NCAP assessment protocol, headform scores are awarded points categorically: maximum points (one point) for HIC<650 (green band); 0.75 points for 650≤ HIC<1,000 (yellow band); 0.5 points for 1,000≤HIC<1,350 (orange band); 0.25 points for 1,350≤HIC<1,700 (brown band); and 0 points for HIC≥1,700 (red band). The agency's planned scoring modifications pertain only to how the five scoring bands are comprised. The changes are shown in table 13 below.

The agency is considering retaining all other aspects of the Euro NCAP headform scoring procedure without change. Scoring would still be based on the average of the grid point values provided by manufacturers for approximately 165 points on the hood, windshield, and A-pillar. Scores would be scaled in accordance with ten verification tests performed by the U.S. NCAP subject to a 10 percent allowance for HIC band cross-over as is done by Euro NCAP. Also unchanged is the Euro NCAP procedure to assign default "red" scores of zero to grid points near A-pillar and full, default "green" scores to grid points in the center of the windshield.

Table 13 – Headform scoring bands: U.S. NCAP (planned) vs. Euro NCAP V8.1

Planned U.S. NCAP			Euro NCAP		Point
Color	HIC	HIC max.	HIC	HIC	Value

	min.		min.	max.	
Green	--	<500	--	<650	1
Yellow	500	<700	650	<1,000	0.75
Orange	700	<1,000	1,000	<1,350	0.5
Brown	1,000	<1,700	1,350	<1,700	0.25
Red	1,700	--	1,700	--	0

Performance limits – Flex-PLI. In the Euro NCAP assessment for each Flex-PLI test point, the scores for tibia bending and ligament elongation are scored separately, with each score ranging from zero to a half point. The tibia bending scores are based only on the highest bending moments measured by the Flex-PLI. Points are determined based on a linear sliding scale between the two performance limits.

The ligament scoring is also based on a linear sliding scale between the two performance limits for elongation of the Flex-PLI's medial collateral ligament (MCL), subject to the ACL/PCL elongation limit, which acts as a qualifier. The ACL/PCL measurements only factor into the score if either the ACL or PCL exceeds 10 mm, in which case no ligament points are awarded. Tibia bending and ligament points are summed to attain a total score for each test. Scores are then averaged across all grid points.

For this program upgrade, NHTSA plans to follow essentially the same assessment procedure. The only modifications the agency is planning pertain to how the upper and lower performance limits are set, as shown table 14 below. All other aspects of the Flex-PLI scoring are unchanged from the Euro NCAP protocol. As in Euro NCAP, NHTSA plans to run three to five tests with the Flex-PLI, depending on the width of the vehicle front-end, and make use of adjacent points and symmetry as employed by Euro NCAP to score all grid points (typically 13-

15 grid points). The scores for all grid points are then averaged to determine the final score for the Flex-PLI assessment, just as it is done in Euro NCAP.

Table 14 – Flex-PLI performance thresholds, U.S. NCAP vs. Euro NCAP

	Tibia bending (Nm)		MCL elongation (mm)		ACL/PCL elongation (mm)
	Lower	Upper	Lower	Upper	Qualifying limit
Euro NCAP	282	340	19	22	10
U.S. NCAP	224	340 (no change)	16.4	22 (no change)	10 (no change)

Performance limits – upper legform. For upper legform testing, the agency is considering using the same process and performance limits as those of Euro NCAP with no changes or modifications. Four separate measurements are considered: three bending moments and the sum of the upper and lower force measurements. Each is assessed individually and assigned a score ranging from 0 to 1 based on a linear sliding scale between upper and lower performance limits. Two sets of performance limits are used: one set for the three bending moments and another set for the sum of forces. The lowest point total among the four determines the score for the grid point tested. These planned performance limits for the upper legform, listed in table 15 below, are identical to the Euro NCAP assessment.

Table 15 – Upper legform performance thresholds (same for U.S. NCAP and Euro NCAP)

Bending Moment (Nm)		Sum of Forces (N)	
Lower	**Upper**	**Lower**	**Upper**
285	350	5000	6000

Also, just as it is done in Euro NCAP, NHTSA plans to conduct three to five tests with the upper legform, depending on the width of the vehicle front-end. The agency plans to make use of adjacent points and symmetry as employed by Euro NCAP to score all grid points (typically 13-15 grid points). The scores for all grid points are then averaged to determine the final score for the upper legform assessment.

2. Pedestrian Crash Avoidance Rating

For the pedestrian crash avoidance score, the vehicle would receive credit for being equipped with PAEB and rear automatic braking technologies, provided that vehicle satisfies the performance requirements for the applicable test scenarios. Both PAEB and rear automatic braking technologies contribute to the crash avoidance portion of the pedestrian rating. Based on NHTSA and other data, the agency examined crash outcomes that resulted in pedestrian or pedalcyclist injury or fatality, which represents the starting target population count.[208] Safety improvement potential can be estimated by multiplying the target population by the system effectiveness. The proportional split between PAEB and rear automatic braking scores was determined by the safety improvement potential of each system. Since the NCAP PAEB tests are conducted at speeds less than 25 mph, the effectiveness presented is valid only at these lower speeds. As the system characterization expands, the effectiveness profile will expand; in other words, as more tests are conducted at increased speeds, more is learned about how the system performs at other speed ranges, supporting an understanding of an expanded system characterization with increased and likely different effectiveness values. The current system effectiveness estimates are valid only at the low speed range. It is possible that future PAEB effectiveness estimates may be represented as a step-function plot correlated to posted speed limit and not a single numeric value. Although vehicle-to-pedalcyclist data is included in the starting target populations, system effectiveness estimates to detect pedalcyclists have not been determined and therefore are not captured within the analysis presented in this notice. Finally,

[208] Annualized target population of vehicle-to-pedestrian (no backing maneuver) and vehicle-to-pedalcyclist crashes (no backing maneuver) using NHTSA FARS and GES for the years 2010-2014.

the agency desires to conduct the NCAP tests with a pedalcyclist target as soon as possible after industry experts complete target development which is currently in progress. At this time, neither NCAP pedestrian crash avoidance test procedure specifies a pedalcyclist test target.

Noteworthy in the pedestrian crash avoidance rating is that the agency is considering stratifying the PAEB test performance into three tiers. This stratification of three tiers is introduced and discussed in detail in the introduction of the PAEB test procedure in an earlier section of this notice titled Crash Avoidance Pedestrian Protection. Opportunity to earn scoring credits within each test tier exists based on system performance. Note that a vehicle may earn credit for a subsequent tier, even if the score is zero percent for the initial or prior tier. The systems contributing to the pedestrian crash avoidance star safety rating would utilize a scorecard like that shown in an example provided in table 16. In this example, the vehicle's pedestrian crash avoidance performance rating would be 23 percent of the possible 50 percent of the pedestrian crash avoidance rating.

Table 16 – Crash Avoidance Portion of the Pedestrian Safety Rating

Crash Avoidance Pedestrian System	PAEB			Rear Automatic Braking
Target Population	937 fatalities[1, 2]			152 fatalities[5]
	17,129 AIS 1-5 injuries[2, 3]			15,000 injuries[5]
Estimated System Effectiveness	52 percent for fatalities[4]			62 percent for fatalities[6]
	18.7 percent reduction in injuries[4]			60 percent reduction in injuries[6]
Safety Improvement Potential	487 fatalities reduced			94 fatalities reduced[7]
	3,203 injuries reduced			9,000 injuries reduced
Maximum Percentage Available	Split of Safety Improvement Potential is calculated as 487 / (487 + 94) = 0.84 for PAEB and 94 / (487 + 94) = 0.16 for Rear Automatic Braking			
	0.84 x 50 percent of Pedestrian Rating = 42 percent			0.16 x 50 percent of Pedestrian Rating = 8 percent
Percentage allocated by Scoring Element	Stage	Proportion	Value	
	Tier 1	60 percent	26 percent	
	Tier 1+2	20 percent	8 percent	
	Tier 1 + 2 +3	20 percent	8 percent	
Example:	Vehicle Equipped with PAEB			Vehicle Equipped with Rear Automatic Braking
Subject Vehicle performance on NCAP tests:	Tier 1	Fail	0 percent	Pass; score = 8 percent
	Tier 1+2	Pass	8 percent	
	Tier 1 + 2 +3	Pass	8 percent	
Subtotals:			16 percent	8 percent

Crash Avoidance Portion of Pedestrian Rating: 16 percent + 8 percent = 24 percent

1 Annualized target population of pedestrians killed in motor vehicle traffic crashes (NHTSA FARS 2010 – 2014 data).
2 For posted speed limits between 5 mph and 25 mph only.
3 Annualized target population of pedestrians injured in motor vehicle traffic crashes (NHTSA GES 2010 – 2014 adjusted data).
4 Yanagisawa, M., Swanson, E., & Najm, W. G. (2014, April). Target crashes and safety benefits estimation methodology for pedestrian crash avoidance/mitigation systems. (Report No. DOT HS 811 998). Washington, DC: National Highway Traffic Safety Administration. Pedestrian Injury Mitigation System Effectiveness. The system effectiveness is derived only from automatic braking and the analysis assumes that the driver did not apply the brakes prior to impact. Potential safety benefits are expected from the ability of the PAEB-equipped vehicle to avoid and mitigate crashes by a reduction in vehicle speed.
5 Annualized estimated target population of pedestrians killed in motor vehicle traffic backover crashes. See 79 FR 19177.
6 Perez, M., et al. (August 2011). Advanced Crash Avoidance Technologies (ACAT) Program - Final Report of the GM-VTTI Backing Crash Countermeasures Project. (Report No. DOT HS 811 452), Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2011/811452.pdf
7 Safety Improvement potential calculated as the target population multiplied by the system effectiveness. 152 multiplied by 0.62 = 94.

3. Assignment of Stars

For this NCAP upgrade, the agency developed a pedestrian protection rating in which the crashworthiness and crash avoidance scores are computed separately, and then combined into a single pedestrian protection star rating. The crashworthiness score is based on the 37.5 percent - 37.5 percent - 25 percent apportioning for headform, Flex-PLI, and upper legform tests as described earlier.

Euro NCAP does not provide separate star ratings for pedestrian safety. Instead, they simply report the pedestrian point score as a percentage. Prior to 2016, the scores were derived from the crashworthiness tests only, with a maximum score of 36 points (24 for the headform tests, 6 each for the Flex-PLI and Upper Legform tests). Thus, the Euro NCAP pedestrian rating was reported as a percentage of the 36 point maximum.

Starting in 2016, Euro NCAP now includes automatic emergency braking (AEB) and Human-Machine Interface (HMI) components. The Euro NCAP pedestrian rating is now based on 42 points. The additional 6 points covers AEB/HMI technologies. It should be noted that Euro NCAP will only include the AEB Pedestrian score when the total passive safety protection score (headform, upper legform and lower legform) is 22 points or higher.

For this NCAP upgrade, the agency is considering a pedestrian rating that is based on equal parts for crashworthiness and crash avoidance because the target populations are similar.[209] Additionally, the agency considers both crashworthiness and crash avoidance countermeasures to be important in preventing fatalities and injuries. In this sense, a pedestrian protection rating up to 5-stars would result from combining two separate ratings: a crashworthiness rating – where up to five half-stars (or 2-½ total stars) may be awarded, and a crash avoidance rating – where (also)

[209] For posted speed limits less than or equal to 40 km/h.

up to five half-stars (or 2-½ total stars) may be awarded. The two sets of stars are added together to determine the overall pedestrian safety rating. Further details on how each set of stars are awarded are described below. As noted, the agency may conduct consumer testing as part of a rulemaking to update the Monroney label. The results of this potential research may change the way the agency presents pedestrian information on the new Monroney label in the future.

Pedestrian Crashworthiness Rating (2-½ stars). The pedestrian crashworthiness stars are derived from the assessment point total as shown in table 17 below. The star bands have been selected based on the results of the six validation test vehicles.

Table 17 – Pedestrian crashworthiness star rating bands.

Lower score (great than or equal to)	Pedestrian Crashworthiness Stars	Upper Score (less than)
0	No stars	15
15	½	30
30	1	50
50	1-½	70
70	2	90
90	2-½	100

Note that there are six separate star categories, including the possibility that no stars are awarded. The nature of the headform assessment essentially ensures that every vehicle will have a non-zero total score (only one test point with HIC<1,700 is needed to achieve this). These include vehicles without any sort of design intent for pedestrian safety. A "no points" band is needed to avoid the perception that such vehicles have inherent pedestrian safety features.

This scoring scheme was applied to the six-vehicle validation test series for demonstration purposes (table 18). Under the planned rating scale for the pedestrian crashworthiness program, the Ford F-150 (14.5 points) would be assigned "no stars" and the Chevy Tahoe (20.4 points) would be awarded just a ½ star. Neither of these vehicles has a

European variant tested by Euro NCAP. Also, as discussed in the December 2015 notice, real-world data indicates that vehicles of this class (large SUV and pickups) are more dangerous to pedestrians.

The formation of the high end of the rating scale also stems from careful consideration of validation testing results. The Nissan Rogue (81.5 points) is an example of a vehicle that has a similar level of performance in Euro NCAP tests (where its variant, the Nissan X-Trail, scored 75 points when Euro NCAP test results are assessed with NHTSA's planned scoring scheme). For this class of vehicles (small or mid-sized SUV, not needing to conform to CFR Part 581, the U.S. Bumper Standard), many U.S. scores will be similar to their Euro NCAP scores since both variants have similar front-ends. Based on NHTSA's planned pedestrian crashworthiness assessment, the Nissan Rogue would be within the 2-star category. In Euro NCAP, the X-Trail variant scored only 17 of 24 points on the headform portion of the assessment, whereas several other vehicles have attained over 20 headform points in Euro NCAP. Setting the upper limit of the band at 90 percent overall would encourage designs for extraordinary performance, including a system such as an air bag that would provide pedestrian protection against the A-pillar and cowl.

Table 18 – Summary of pedestrian crashworthiness scores in validation test vehicles

Validation Test Vehicles	**Headform Score** (max 37.5)	**Flex PLI Score** (max 37.5)	**Upper Legform Score** (max 25)	**Pedestrian Crashworthiness Overall Score** (max 100)	**Pedestrian Crashworthiness Stars** (max 2-½ stars)
2016 Nissan Rogue	21.3	35.2	25.0	81.5	2
2016 Honda Fit	24.0	0	25.0	49.0	1
2016 Chevrolet Malibu Limited	18.8	9.7	14.2	42.6	1
2015 Toyota Sienna	18.8	0	10.2	29.0	½
2016 Chevrolet Tahoe	17.0	0	3.3	20.4	½
2015 Ford F-150	9.5	0	5.0	14.5	no stars

Pedestrian Crash Avoidance Rating (2-½ stars). The pedestrian crash avoidance stars would be derived from the assessment percentage shown in table 19 below. The percentage totals range from 0-50. The star bands have been chosen based on the agency's expectations of system performance during NCAP testing. Note that there are six separate star categories, including the possibility that zero stars are awarded.

Table 19 – Pedestrian crash avoidance star rating bands

Lower score (greater than or equal to)	Pedestrian Crash Avoidance Stars	Upper Score (less than)
0	0 stars	1
1	½	10
10	1	20
20	1-½	30
30	2	40
40	2-½	50

Unlike the crashworthiness assessment, a zero score in the crash avoidance assessment is possible. If a vehicle is not equipped with PAEB or rear automatic braking systems, it will score zero percent. Among the vehicles used in the validation test series, only one vehicle – the 2016 Chevrolet Malibu – was equipped with a PAEB system (available as an optional package on certain trim levels and standard on the 2LT trim level). None of the validation vehicles were equipped with rear automatic braking systems. However, the agency recently tested three production vehicle make/models equipped with rear automatic braking systems.[210]

[210] Docket No. NHTSA-2015-0119, "Rear Automatic Braking Feature Confirmation Test for New Car Assessment Program - Proposed Test Procedure Assessment." Mazzae, E.N., Baldwin, G.H.S., & Andrella, Adam T. (2016, December).

For illustrative purposes, table 20 displays the crash avoidance star rating for the six vehicles in the agency's validation test series, where only the Chevrolet Malibu has a non-zero rating. For the Chevrolet Malibu, the agency assumed that the PAEB system received full performance scores. The agency did not conduct the draft NCAP crash avoidance tests, nor was a self-generated assessment obtained from General Motors.

Although table 20 gives the appearance of an "all or nothing" rating, the agency is confident that ratings would be dispersed in each of the star bands when system performance is assessed through the NCAP test procedures. In support of this notice, the agency performed an analytical exercise to rate the same six vehicle models that were tested under the planned crashworthiness rating category. When selecting these vehicles, the agency did not consider whether they would be available or equipped with pedestrian crash avoidance systems. Based on manufacturer supplied responses to the agency's annual request of new model year vehicle information, at least 15 manufacturers offered PAEB systems as optional equipment on more than 50 MY 2016 models. Manufacturers offered PAEB systems as standard equipment on 15 MY 2017 models and as optional equipment on 163 models. The vehicles in the NCAP validation testing series represent a small sample. The agency believes that ratings would be more dispersed in each of the star bands when system performance is assessed through the NCAP test procedures. This planned rating scale for the pedestrian crash avoidance program would encourage full development of crash avoidance technologies for pedestrian safety and it will also encourage manufacturers to add avoidance technologies to their model lines to prevent a "zero-star" rating.

Table 20 – Summary of pedestrian crash avoidance rating for validation test vehicles

Vehicle	**Rear automatic braking**	**PAEB** (max. 42%)	**Pedestrian Crash Avoidance Rating** (max. 2-½ stars)

	(max. 8%)		
2016 Nissan Rogue	0	0	0-stars
2016 Honda Fit	0	0	0-stars
2016 Chevrolet Malibu	0	42	2-½*
2015 Toyota Sienna	0	0	0-stars
2016 Chevrolet Tahoe	0	0	0-stars
2015 Ford F-150	0	0	0-stars

Overall pedestrian protection rating. The total pedestrian star rating of a vehicle is simply the sum of the individual pedestrian crashworthiness and crash avoidance stars achieved by that vehicle. For illustrative purposes, the ratings applied to the validation test vehicles are shown in table 21.

Table 21 – Summary of full pedestrian rating in NHTSA validation test vehicles

Vehicle	**Pedestrian Crashworthiness Stars** (max. 2-½ stars)	**Pedestrian Crash Avoidance Stars** (max. 2-½ stars)	**Overall Pedestrian Protection Stars** (max 5)
2016 Nissan Rogue	2	0 stars	2
2016 Honda Fit	1	0 stars	1
2016 Chevrolet Malibu	1	2-½*	3-½
2015 Toyota Sienna	½	0 stars	½
2016 Chevrolet Tahoe	½	0 stars	½
2015 Ford F-150	0 stars	0 stars	0 stars

**(Standard=2LT; option = 1LT, Hybrid, Premier)*

D. Overall Vehicle Rating System

The agency is considering an overall vehicle rating that is comprised of the following weighing proportions: 50 percent, 40 percent, and 10 percent for the crashworthiness, crash avoidance and pedestrian categories, respectively. Since pedestrian fatalities accounted for 16 percent of all fatalities that are related to motor vehicle crashes in 2014, the agency believes that

10 percent of the overall vehicle rating is appropriate for the new planned pedestrian protection rating category. The remaining 90 percent is divided among the two other rating categories, crashworthiness and crash avoidance, with the crashworthiness category having a little more influence (50/40 instead of 45/45) on the overall rating. The agency reasons that the majority of vehicles on the road do not have advanced crash avoidance technologies, and since crashes will continue to occur for the foreseeable future, the crashworthiness protection component remains a vital part of this NCAP upgrade. Once more vehicles are equipped with advanced crash avoidance technologies, and more crashes are avoided due to advanced crash avoidance technologies, a shift in the distribution could be more appropriate. Similar to the pedestrian protection rating category, the agency plans to introduce the crash avoidance program as part of the 5-star rating system for the first time in the history of the program.

The agency is requesting comments on the planned weighting proportions for the overall vehicle rating as well as the need for providing an overall vehicle rating for consumers with the inclusion of 2 new rating categories – crash avoidance and pedestrian protection. The allotments of the new 5-star rating system are purposely factored by ten for convenience in assigning half-star ratings. As such, 5 stars may be thought of as ten half-stars with the crashworthiness component contributing up to five half-stars, the crash avoidance component contributing up to four half-stars, and the pedestrian component contributing a single half-star.

For overall ratings, the sub-rating systems apply a different set of thresholds than the individual ratings. This is explained in more detail below.

1. Crashworthiness Category (Five half-stars)

Up to five half-stars towards the overall vehicle rating may be earned based on the 0-100 point score for the crashworthiness assessment. The 5-star rating for crashworthiness-only was discussed earlier and is shown in table 9. For the overall rating, up to 2-½ stars accounting for crashworthiness safety are awarded as shown in table 22. Note that for any given vehicle, there is only one crashworthiness point total; that same point total is used to determine the CW-only stars (using table 9) and the CW stars that are applied to the overall rating (using table 22). Also, the agency notes that a score above 10 points is needed to attain a half-star to be applied to the overall vehicle rating. However, in the individual crashworthiness rating, only 5 points are needed for a half star minimum.

Table 22 – Crashworthiness rating bands for the overall star rating

Lower score (great than or equal to)	Crashworthiness Stars	Upper Score (less than)
0	No stars	10
10	½	20
20	1	40
40	1-½	60
60	2	80
80	2-½	100

2. Crash Avoidance Category (Four half-stars)

As shown in table 23 below, up to four half-stars may be earned based on the 0-100 percent score for the crash avoidance assessment and contribution to the overall rating. Note that a score above 10 percent is also needed to attain a half-star to be applied to the overall rating. This overall scale differs from the individual crash avoidance rating scale discussed elsewhere. For example, in the individual crash avoidance rating scale (table 12), any non-zero score will earn one star minimum and the maximum score is the traditional 5-star scale.

Table 23 – Crash avoidance rating bands for the overall star rating

Lower score (great than or equal to)	Crash Avoidance Stars for Overall Rating	Upper Score (less than)

0	0-stars	10
10	½	30
30	1	50
50	1½	70
70	2	100

3. Pedestrian Protection Category (A single half-star)

To attain the pedestrian half-star towards the overall rating, the individual pedestrian rating (which combines separate pedestrian crashworthiness and crash avoidance ratings) must be 3-½ stars or greater. The relatively high threshold for the overall rating reflects a higher recognition standard relative to the individual pedestrian rating because it is necessary to ensure that a vehicle employs crashworthiness and crash avoidance technologies for pedestrian safety in order to gain an overall pedestrian protection 5-star rating, which would indicate the highest level of safety for vehicle occupants and pedestrians.

4. Combined Vehicle Rating (Ten half-stars = 5 stars)

Table 24 shows the overall ratings for the agency's six validation test vehicles. As noted previously, these vehicles all received 4 or 5 stars for an overall vehicle score under the current rating system. The point totals shown are the same as those presented in the previous sections for demonstrating validation test results. For the overall vehicle rating, table 24 below combines the three components additively. For illustrative purposes, two sets of ratings are provided for each vehicle model: one for trim levels that include the most crash avoidance options, and one for trim levels that contain the fewest. As explained earlier, the crash avoidance scores shown are assumed based on full performance; the agency did not actually assess these vehicles.

Table 24 – Overall vehicle ratings for six validation test vehicles

Validation Test Vehicles	Trim Level	CW Sub-score[1]	CW Overall Stars[2]	CA Sub-score[1]	CA Overall Stars[2]	Ped Sub-Stars[1]	Ped Overall Stars[2]	**Total Vehicle Rating (Stars)**

2016 Chevrolet Malibu	Limited[3] LT	52.70	1-½	27	½	1	None	**2**
	Premier with options			79	2	3-½	½	**4**
2016 Nissan Rogue	S	45.50	1-½	27	½	2	None	**2**
	SL with options			42	1	2	None	**2-½**
2016 Honda Fit	LX, EX, EX-L	42.20	1-½	22	½	1	None	**2**
2015 Toyota Sienna	L, LE std	44.80	1-½	27	½	½	None	**2**
	SE, XLE with options			42	1	½	None	**2-½**
2016 Chevrolet Tahoe	LS std	56.70	1-½	16	½	½	None	**2**
	LTZ with options			55	1-½	½	None	**3**
2016 Ford F-150	XL, XLT std	53.70	1-½	22	½	None	None	**2**
	Platinum with options, Limited			61	1-½	None	None	**3**

[1]Based on rating scale determined for individual crashworthiness, crash avoidance, and pedestrian protection categories
[2]Based on rating scale determined for the overall vehicle rating (combined NCAP rating).
[3]This version was used for the crashworthiness as well as the pedestrian crashworthiness validation tests.

VI. Conclusion

This supplemental notice intends to inform and provide the public with: (1) updates to information and materials that were included in the December 2015 RFC notice, (2) new agency research findings since the publication of the December 2015 notice, and (3) the agency's considerations about the planned rating system for each of the rating categories (crashworthiness, crash avoidance, and pedestrian) as well as the overall vehicle rating that comprises these three categories. Supporting documents for these updates and new materials are included in the docket of this notice. NHTSA is requesting comment on these supporting documents as well as today's notice in its entirety. The agency expects comments on these materials to be received within the time period indicated in this notice. As indicated previously, the agency plans to address comments responding to both the December 2015 notice and this supplemental notice in its final decision document. Thus, the agency plans to move the implementation of this NCAP upgrade to 2019 beginning with MY 2020 vehicles.

VII. Public Participation

How do I prepare and submit comments?

Your comments must be written and in English. To ensure that your comments are filed correctly in the docket, please include the docket number of this document in your comments.

Your comments must not be more than 15 pages long (49 CFR 553.21). NHTSA established this limit to encourage you to write your primary comments in a concise fashion. However, you may attach necessary additional documents to your comments. There is no limit on the length of the attachments.

Please submit one copy (two copies if submitting by mail or hand delivery) of your comments, including the attachments, to the docket following the instructions given above under ADDRESSES. Please note, if you are submitting comments electronically as a PDF (Adobe) file, NHTSA asks that the documents submitted be scanned using an Optical Character Recognition (OCR) process, thus allowing the agency to search and copy certain portions of your submissions.

How do I submit confidential business information?

If you wish to submit any information under a claim of confidentiality, you should submit three copies of your complete submission, including the information you claim to be confidential business information, to the Office of the Chief Counsel, NHTSA, at the address given above under FOR FURTHER INFORMATION CONTACT. In addition, you may submit a copy (two copies if submitting by mail or hand delivery), from which you have deleted the claimed confidential business information, to the docket by one of the methods given above under

ADDRESSES. When you send a comment containing information claimed to be confidential business information, you should include a cover letter setting forth the information specified in NHTSA's confidential business information regulation (49 CFR Part 512).

Will the agency consider late comments?

NHTSA will consider all comments received before the close of business on the comment closing date indicated above under DATES. To the extent possible, the agency will also consider comments received after that date.

Please note that even after the comment closing date, we will continue to file relevant information in the docket as it becomes available. Accordingly, we recommend that interested people periodically check the docket for new material.

You may read the comments received at the address given above under ADDRESSES. The hours of the docket are indicated above in the same location. You may also see the comments on the Internet, identified by the docket number at the heading of this notice, at *www.regulations.gov*.

Anyone is able to search the electronic form of all comments received into any of our dockets by the name of the individual submitting the comment (or signing the comment, if submitted on behalf of an association, business, labor union, etc.). You may review DOT's complete Privacy Act Statement in the Federal Register published on April 11, 2000 (65 FR 19477-78), or you may visit *www.dot.gov/privacy.html*.

VIII. Appendices

Appendix I – FARS Data

NHTSA examined Fatality Analysis Reporting System (FARS) real-world data, limited to calendar years 2010-2014, in support of this notice.

The frontal crashes are comprised of tow-away events without rollovers. Impacts angles were restricted to between 11 and 1 o'clock. All fatalities in these crashes were limited to 3 point belted occupants 13 and older. Front row fatalities are comprised of occupants seated in the driver and right passenger position and rear seat occupants were not restricted to just the outboard positions. Table I-1 shows the numbers of frontal fatalities by seating position: driver, right front passenger, and all second row occupants. Frontal crashes were responsible for almost 60% of the fatalities in this data set.

The side crash data is also comprised of tow-away, non-rollover vehicles. Impact angles were restricted to between the angles of 8 and 10 o'clock and between the angles of 2 and 4 o'clock. For vehicle-to-vehicle conditions the most harmful event must have included contact with another vehicle and for vehicle-to-pole conditions the most harmful event must have included contact with a tall, narrow object such as a tree or pole. This approach was applied to both belted and unbelted near-side occupants involved in side crashes. All occupants younger than 13 in the front row or eight in the rear row or those completely ejected from the vehicle were excluded. Table I-1 shows the numbers of side fatalities for vehicle-to-vehicle near-side front occupants (drivers and right front passengers), vehicle-to-vehicle near-side second row occupants, and vehicle-to-pole front occupants (drivers and right front passengers). Fatalities in these side impact crashes amounted to over 40% of this data set.

To generate the date shown in Table I-2, the same total number of fatalities (6,378) were divided to show the fatality counts by seating position in the vehicle regardless of crash type.

The data in Table I-2 shows the breakdown between drivers, right front passengers, and rear seat passengers involved in fatal crashes. Drivers, due to their exposure in every crash, comprise the majority of fatalities.

Table I-1. FARS Data from 2010-2014: Totals by Crash Type and Occupant Location

Row	Crash Type and Occupant Location	2010-2014 Average Fatalities	Percent of Total Fatalities
1	Frontal, Driver - 3 pt belt	3,066.2	48.1 percent
2	Frontal, Right Front Passenger (RFP)- 3 pt belt	643.8	10.1 percent
3	Frontal, 2nd Row Passenger - 3 pt belt	109.6	1.7 percent
	Total Frontals	*3,819.6*	*59.9 percent*
4	Side Pole, Driver/RFP - Nearside	575.2	9.0 percent
5	Side VtV (MDB-like), Driver/RFP - Nearside	1,858.6	29.1 percent
6	Side VtV (MDB-like), 2nd Row Passenger - Nearside	124.6	2.0 percent
	Total Sides	*2,558.4*	*40.1 percent*
	Total	**6,378.0**	**--**

Source: FARS 2010-2014

Table I-2. FARS Data from 2010-2014: Totals by Occupant Location

Totals by Occupant Location	2010-2014 Average Fatalities	Percent of Total Fatalities
Total Drivers (summation of rows 1, 4, and 5 of Table I-1)	5,500.0	86.2 percent
Total RFPs (row 2 of Table I-1)	643.8	10.1 percent
Total Rear Seat (summation of rows 3 and 6 of Table I-1)	234.2	3.7 percent
Total	**6,378.0**	**--**

Source: FARS 2010-2014

Appendix II – THOR 50th Percentile Male Injury Risk Curves Planned for Use in this NCAP Upgrade

Criterion [ref]	Calculation	Variable	Variable Definition	Risk Function
HIC_{15} [NCAP Final Decision Notice, 2008]	$HIC_{15} = \left\| (t_2 - t_1)\left[\frac{1}{(t_2 - t_1)}\int_{t_1}^{t_2} a(t)dt\right]^{2.5} \right\|_{max}$	t_1	Beginning of time window in s	$p(AIS \geq 3) = \Phi\left[\frac{\ln(HIC_{15}) - 7.45231}{0.73998}\right]$
		t_2	End of time window in s	
		$a(t)$	Head CG resultant acceleration in g, x, y, z components filtered at CFC1000	
$BrIC$ [Takhounts, 2013]	$BrIC = \sqrt{\left(\frac{\max(\|\omega_x\|)}{\omega_{xC}}\right)^2 + \left(\frac{\max(\|\omega_y\|)}{\omega_{yC}}\right)^2 + \left(\frac{\max(\|\omega_z\|)}{\omega_{zC}}\right)^2}$	$\omega_{[x,y,z]}$	Angular velocity of the head about the local [x, y, or z] axis, in rad/s, filtered at CFC60	$p(AIS \geq 4) = 1 - e^{-\left(\frac{BrIC - 0.523}{0.647}\right)^{1.8}}$
		$\omega_{[x,y,z]C}$	Critical angular velocities in rad/s	
		ω_{xC}	66.25 rad/s	
		ω_{yC}	56.45 rad/s	
		ω_{zC}	42.87 rad/s	
N_{ij} [Injury Criteria for the THOR 50th Male ATD]	$N_{ij} = \frac{F_z}{F_{zc}} + \frac{M_y}{M_{yc}}$	F_z	Z-axis force measured at upper neck load cell in N, filtered at $CFC600$	$p(AIS \geq 2) = \frac{1}{1 + e^{(4.3085 - 5.4079 N_{ij})}}$ $p(AIS \geq 3) = \frac{1}{1 + e^{(4.9372 - 4.5294 N_{ij})}}$
		F_{zc}	Critical force (tension or compression) in N [4200/-6400]	
		M_y	Y-axis moment measured at upper neck load cell Nm, filtered at CFC600	
		M_{yc}	Critical moment (flexion or extension) in Nm [88.1/-117]	
Multi-point Thoracic Injury Criterion – Peak Resultant Deflection	$R_{max} = max(UL_{max}, UR_{max}, LL_{max}, LR_{max})$ where $[U/L\|R/L]_{max} = max\left(\sqrt{[L/R]X^2_{[U/L]S} + [L/R]Y^2_{[U/L]S} + [L/R]Z^2_{[U/L]S}}\right)$	R_{max}	Overall peak resultant deflection in mm	$p(AIS \geq 3) = 1 - e^{-\left(\frac{R_{max}}{59.865}\right)^{2.7187}}$
		$\begin{bmatrix} U/L\| \\ R/L \end{bmatrix}_{max}$	Peak resultant deflection of the [upper/lower | left/right] quadrant in mm	

[Injury Criteria for the THOR 50th Male ATD]		$[L/R]\,[X/Y/Z]^2_{[U/L]S}$	Time-history of the [left/right] chest deflection along the [X/Y/Z] axis relative to the [upper/lower] spine segment in mm, filtered at CFC180	
Abdomen Compression [Injury Criteria for the THOR 50th Male ATD]		δmax	Peak X-axis deflection of the left or right abdomen in mm, filtered at CFC600	$p(AIS \geq 3) = \frac{1}{1+e^{(7.849-0.0886\delta_{max})}}$
Peak Resultant Acetabulum Force [Injury Criteria for the THOR 50th Male ATD]	$F_{AR} = \sqrt{{F_x}^2 + {F_y}^2 + {F_z}^2}$	F_{AR}	Peak resultant acetabulum force in *kN*, x, y, z, components filtered at CFC600	$p(Hip\ fracture) = \Phi\left[\frac{\ln 1.429F_{AR} - 1.6058}{0.2339}\right]$
Femur Axial Load [Injury Criteria for the THOR 50th Male ATD]		F_{LC}	peak compressive Z-axis force, in *kN*, measured in the left and right femur, filtered at CFC600	$p(AIS \geq 2) = \frac{1}{1+e^{5.7949-0.6748F_{LC}}}$
Distal (Lower) Tibia Axial Force [Injury Criteria for the THOR 50th Male ATD]		$F_{lowertibia}$	largest compressive z-axis force, in *kN*, measured in the left and right lower tibia, filtered at CFC600	$p(AIS \geq 2) = \frac{1}{1+e^{(3.9121-0.48F_{lower\ tibia})}}$
Proximal (Upper) Tibia Axial Force [Injury Criteria for the THOR 50th Male ATD]		$F_{uppertibia}$	largest compressive z-axis force, in *kN*, measured in the left and right upper tibia, filtered at CFC600	$p(AIS \geq 2) = \frac{1}{1+e^{(5.6654-0.8189F_{upper\ tibia})}}$
Tibia Bending Moment [Injury Criteria for the THOR 50th Male ATD]		M_{res}	largest resultant moment, in *Nm*, calculated from the x-axis and y-axis moments measured in the left and right upper and lower tibia, filtered at CFC600	$p(AIS \geq 2) = 1 - e^{-e^{\left(\frac{lnM_{res}-5.8492}{0.2965}\right)}}$

Appendix III – Hybrid III 5th Percentile Female Injury Risk Curves Planned for Use in this NCAP Upgrade

Criterion [ref]	Calculation	Variables	Variable Definition	Risk Function
HIC_{15} [NCAP Final Decision Notice, 2008]	$HIC_{15} = \left\| (t_2 - t_1)\left[\frac{1}{(t_2 - t_1)}\int_{t_1}^{t_2} a(t)dt\right]^{2.5} \right\|_{max}$	t_1	Beginning of time window in s	$p(AIS \geq 3) = \Phi\left[\frac{\ln(HIC_{15}) - 7.45231}{0.73998}\right]$
		t_2	End of time window in s	
		$a(t)$	Head CG resultant acceleration in g, x, y, z components filtered at CFC1000	
$BrIC$ [Takhounts, 2013]	$BrIC = \sqrt{\left(\frac{\max(\|\omega_x\|)}{\omega_{xC}}\right)^2 + \left(\frac{\max(\|\omega_y\|)}{\omega_{yC}}\right)^2 + \left(\frac{\max(\|\omega_z\|)}{\omega_{zC}}\right)^2}$	$\omega_{[x,y,z]}$	Angular velocity of the head about the local [x, y, or z] axis, in rad/s, filtered at CFC60	$p(AIS \geq 4) = 1 - e^{-\left(\frac{BrIC - 0.523}{0.647}\right)^{1.8}}$
		$\omega_{[x,y,z]C}$	Critical angular velocities in rad/s	
		ω_{xC}	66.25 rad/s	
		ω_{yC}	56.45 rad/s	
		ω_{zC}	42.87 rad/s	
N_{ij}	$N_{ij} = \frac{F_z}{F_{zc}} + \frac{M_y}{M_{yc}}$	F_z	Z-axis force measured at upper neck load cell in N, filtered at CFC600	$p(AIS \geq 3) = 1 - e^{\left(-\left(\frac{N_{ij}}{1.3933}\right)^{2.8816}\right)}$
		F_{zc}	Critical force (tension or compression) in N [4287/-3880]	
		M_y	Y-axis moment measured at upper neck load cell Nm, filtered at CFC600	
		M_{yc}	Critical moment (flexion or extension) in Nm [155/-67]	
Chest Deflection [NCAP Final Decision Notice, 2008]		δ	Peak X-axis deflection at chest potentiometer in mm, filtered at CFC600	$p(AIS \geq 3) = \frac{1}{1 + e^{12.597 - 0.05861*35 - 1.568*\left(\frac{\delta}{0.817}\right)^{0.4612}}}$
Femur Axial Force [NCAP Final Decision Notice, 2008]		F_z	Z-axis femur force in kN, filtered at CFC600	$p(AIS \geq 2) = \frac{1}{1 + e^{5.7949 - 0.7619F_z}}$

Appendix IV – WorldSID 50th Percentile Male Injury Risk Curves Planned for Use in this NCAP Upgrade

Criterion [ref]	Calculation	Variables	Variable Definition	Risk Function
HIC_{15} [NCAP Final Decision Notice, 2008]	$HIC_{15} = \left\| (t_2 - t_1)\left[\frac{1}{(t_2 - t_1)}\int_{t_1}^{t_2} a(t)dt\right]^{2.5} \right\|_{max}$	t_1	Beginning of time window in s	$p(AIS \geq 3) = \Phi\left[\frac{\ln(HIC_{15}) - 7.45231}{0.73998}\right]$
		t_2	End of time window in s	
		$a(t)$	Head CG resultant acceleration in g, x, y, z components filtered at CFC1000	
$BrIC$ [Takhounts, 2013]	$BrIC = \sqrt{\left(\frac{\max(\lvert\omega_x\rvert)}{\omega_{xC}}\right)^2 + \left(\frac{\max(\lvert\omega_y\rvert)}{\omega_{yC}}\right)^2 + \left(\frac{\max(\lvert\omega_z\rvert)}{\omega_{zC}}\right)^2}$	$\omega_{[x,y,z]}$	Angular velocity of the head about the local [x, y, or z] axis, in rad/s, filtered at CFC60	$p(AIS \geq 4) = 1 - e^{-\left(\frac{BrIC - 0.523}{0.647}\right)^{1.8}}$
		$\omega_{[x,y,z]C}$	Critical angular velocities in rad/s	
		ω_{xC}	66.25 rad/s	
		ω_{yC}	56.45 rad/s	
		ω_{zC}	42.87 rad/s	
Shoulder Force [Petitjean, 2012]		F_Y	Y-axis maximum shoulder load in N, filtered at CFC600	$p(AIS \geq 2) = 1 - e^{-\left(\frac{F_Y}{e^{8.144 - 0.006*age}}\right)^{7.41}}$
Skeletal Thoracic Injury [Stammen, 2016]		δ_{max}	Y-axis maximum thoracic or abdominal rib deflection in *mm*, filtered at CFC600	$p(AIS \geq 3) = \frac{1}{1 + e^{\left(\frac{-(\mathrm{LN}(\delta_{\max}) - (4.9079 - 0.0195*age))}{e^{-1.9468}}\right)}}$
Soft Tissue Abdominal Injury [Stammen, 2016]		δ_{max}	Y-axis maximum abdominal rib deflection in *mm*, filtered at CFC600	$p(AIS \geq 2) = 1 - e^{-\left(\frac{\delta_{max}}{e^{5.1727 - 0.0182*age}}\right)^{\frac{1}{e^{-2.4408}}}}$
Pubic Force [Petitjean, 2012]		F_Y	Y-axis pubic force in N, filtered at CFC600	$p(AIS \geq 2) = 1 - e^{-\left(\frac{F_Y}{e^{8.775 - 0.014*age}}\right)^{4.60}}$
Sacroiliac Force [Stammen, 2016]		F_{res}	Maximum sacroiliac resultant force in N, filtered at CFC600	$p(AIS \geq 2) = \frac{1}{1 + e^{\left(-\frac{LN(F_{res}) - (9.159 - 0.014*age)}{e^{-1.432}}\right)}}$

Appendix V – SID-IIs 5th Percentile Female Injury Risk Curves Planned for Use in this NCAP Upgrade

Criterion [ref]	Calculation	Variables	Variable Definition	Risk Function
HIC_{15} [NCAP Final Decision Notice, 2008]	$HIC_{15} = \left\| (t_2 - t_1)\left[\frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} a(t)dt\right]^{2.5} \right\|_{max}$	t_1	Beginning of time window in s	$p(AIS \geq 3) = \Phi\left[\frac{\ln(HIC_{15}) - 7.45231}{0.73998}\right]$
		t_2	End of time window in s	
		$a(t)$	Head CG resultant acceleration in g, x, y, z components filtered at CFC1000	
$BrIC$ [Takhounts, 2013]	$BrIC = \sqrt{\left(\frac{\max(\|\omega_x\|)}{\omega_{xC}}\right)^2 + \left(\frac{\max(\|\omega_y\|)}{\omega_{yC}}\right)^2 + \left(\frac{\max(\|\omega_z\|)}{\omega_{zC}}\right)^2}$	$\omega_{[x,y,z]}$	Angular velocity of the head about the local [x, y, or z] axis, in rad/s, filtered at CFC60	$p(AIS \geq 4) = 1 - e^{-\left(\frac{BrIC - 0.523}{0.647}\right)^{1.8}}$
		$\omega_{[x,y,z]C}$	Critical angular velocities in rad/s	
		ω_{xC}	66.25 rad/s	
		ω_{yC}	56.45 rad/s	
		ω_{zC}	42.87 rad/s	
Thoracic Rib Deflection [Kuppa, 2006]		δ_{max}	Y-axis maximum thoracic rib deflection in *mm*, filtered at CFC600	$p(AIS \geq 3) = \frac{1}{1 + e^{5.8627 - 0.15498 * \delta_{max}}}$
Alternative Thoracic Rib Deflection [Irwin, 2016]		δ_{max}	Y-axis maximum thoracic rib deflection in *mm*, filtered at CFC600	$p(AIS \geq 3) = NORMDIST(\delta_{max}, \mu = 45, \sigma = 8.6)$
Abdominal Rib Deflection [Kuppa, 2006]		δ_{max}	Y-axis maximum abdomen rib deflection in *mm*, filtered at CFC600	$p(AIS \geq 4) = \frac{1}{1 + e^{8.9798 - 0.1349 * \delta_{max}}}$
Acetabular + Iliac Force [NCAP Final Decision Notice, 2008]	$F_T = F_{Ya} + F_{Yi}$	F_{Ya}	Y-axis acetabular load in *N*, filtered at CFC600	$p(AIS \geq 2) = \frac{1}{1 + e^{6.3055 - 0.00094 * F_T}}$ *where F_T is the total sum of the acetabular and iliac force in Newtons*
		F_{Yi}	Y-axis iliac load in *N*, filtered at CFC600	

Appendix VI – Pedestrian Injury Risk Functions

Criterion [ref]	Calculation	Variables	Variable Definition	Risk Function
HIC_{15} [NCAP Final Decision Notice, 2008]	$HIC_{15} = \left\| (t_2 - t_1)\left[\frac{1}{(t_2 - t_1)}\int_{t_1}^{t_2} a(t)dt\right]^{2.5} \right\|_{max}$	t_1	Beginning of time window in s	$p(AIS \geq 3) = \Phi\left[\frac{\ln(HIC_{15}) - 7.45231}{0.73998}\right]$
		t_2	End of time window in s	
		$a(t)$	Head CG resultant acceleration in g, x, y, z components filtered at CFC1000	
Tibia Fracture [Takahashi, 2012]		$M_{FlexLeg}$	Maximum X-axis tibia bending moment in *Nm*, filtered at CFC600	$p(AIS \geq 2) = 1 - \exp[-\exp\{5.77458 \ln\left(\frac{M_{FlexLeg} + 72.798}{1.259}\right) - 34.51175\}]$
MCL Injury [Takahashi, 2012]		$\delta_{FlexLeg}$	MCL elongation in *mm*, filtered at CFC600	$p(AIS \geq 2) = 1 - \exp[-\exp\{9.387 \ln(\delta_{FlexLeg}) - 29.03\}]$
Femur Fracture		$M_{Impactor}$	Maximum X-axis bending moment in *Nm*, filtered at CFC600	See "Pedestrian Injury Risk Functions for the New Car Assessment Program (NCAP)" Report on the docket for details about how performance limits were derived by Euro NCAP from upper legform injury risk functions.
Pelvis Fracture		$F_{Impactor}$	Y-axis sum of forces in N , filtered at CFC600	See "Pedestrian Injury Risk Functions for the New Car Assessment Program (NCAP)" Report on the docket for details about how performance limits were derived by Euro NCAP from upper legform injury risk functions.

Appendix VII - Results of Full Frontal Fleet Testing

		Vehicle	2016 Chevrolet Malibu Limited	2016 Nissan Rogue	2016 Honda Fit	2016 Toyota Sienna	2016 Chevrolet Tahoe	2016 Ford F-150 Supercrew	2015 Mazda 3	2015 Toyota Highlander
		Test Number	9567	9569	9566	9570	9568	9571	9336	9334
Driver THOR 50^{th}	**Head**	**HIC15**	252	448	314	341	365	244	229	259
		BrIC	0.72	0.70	0.85	0.80	0.69	0.53	0.56	0.59
	Neck	**Nij**	0.40	0.47	0.29	0.41	0.50	0.31	0.41	0.63
	Chest	**Chest Resultant Deflection (mm)**	38	49	48	53	54	40	51	66
	Abdomen	**Abdomen Deflection (mm)**	65	58	64	62	57	64	54	64
	KTH	**Acetabulum Force - Left (N)**	1148	3384	1531	1056	1905	1476	2636	2270
		Acetabulum Force - Right (N)	921	2937	1599	1643	2007	943	2518	1597
		Femur Force - Left (N)	1489	6727	1996	1787	2409	3712	3744	2425
		Femur Force - Right (N)	3033	6244	2502	2909	4168	3030	3891	3867
	Lower Leg	**Tibia Upr Left - F (N)**	1853	1034	1373	1222	1058	1247	2048	1846
		Tibia Upr Right - F (N)	2555	770	1285	3627	2736	2133	1435	1864
		Tibia Lwr Left - F (N)	2577	1670	2811	1960	1357	1891	3101	2939
		Tibia Lwr Right - F (N)	3424	2176	4616	5076	4600	2637	1862	2336
		Tibia Upr Left - Rsltnt Moment (Nm)	64	93	105	40	83	74	54	82
		Tibia Upr Right - Rsltnt Moment (Nm)	67	88	67	58	94	46	51	111
		Tibia Lwr Left - Rsltnt Moment (Nm)	39	68	66	29	68	49	38	55
		Tibia Lwr Right - Rsltnt Moment (Nm)	42	65	66	50	77	53	56	58
Right Front Pass HIII-5F	**Head**	**HIC15**	168	277	152	337	202	379	241	235
		BrIC	0.60	0.69	0.81	0.43	0.87	0.45	0.52	0.58
	Neck	**Nij**	0.52	0.54	0.57	0.52	0.55	0.29	0.45	0.51
	Chest	**Chest Deflection (mm)**	16	34	23	16	18	18	18	23
	KTH	**Femur Force - Left (N)**	71	766	71	770	428	159	167	625
		Femur Force - Right (N)	108	69	70	358	181	149	72	104
Right Rear Pass HIII-5F	**Chest**	**Chest Deflection (mm)**	41	51	48	45	39	41	39	56[1]

[1]Maximum chest potentiometer output.

Appendix VIII - Results of Frontal Oblique Fleet Testing

		Vehicle	2016 Chevrolet Malibu Limited	2016 Nissan Rogue	2016 Honda Fit	2016 Toyota Sienna	2016 Chevrolet Tahoe	2016 Ford F-150 Supercrew	2014 Mazda 3	2014 Honda Accord	2014 Mazda CX-5	2014 Subaru Forester	2012 Volvo S60	2015 Toyota Highlander
		Test Number	9573	9574	9572	9585	9586	9587	8787	8789	8788	8478	8488	9481
Driver THOR 50M	**Head**	**HIC15**	191	310	292	278	103	165	264	189	206	190	151	175
		BrIC	1.18	0.70	1.15	0.84	0.84	1.28	1.19	0.61	0.68	0.82	1.10	0.66
	Neck	**Nij**	0.41	0.51	0.54	0.53	0.29	0.29	0.47	0.40	0.50	0.50	0.46	0.52
	Chest	**Chest Resultant Deflection (mm)**	54.4	57.0	51.3	53.0	50.4	43.4	48.1	53.9	49.5	52.9	42.7	62.3
	Abdomen	**Abdomen Deflection (mm)**	57.0	60.1	65.2	67.7	57.1	60.1	65.0	60.8	52.3	---[1]	---[1]	64.7
	KTH	**Acetabulum Force - Left (N)**	1823	3958	4673	2195	2105	1828	1555	1730	1259	1924	2172	1762
		Acetabulum Force - Right (N)	1846	2494	2127	2693	3392	1052	2448	2074	2153	1538	3933	2541
		Femur Force - Left (N)	4921	6522	9184	3375	2913	3765	2401	3373	2918	2697	3574	2209
		Femur Force - Right (N)	3454	5119	4463	4425	6451	2477	2078	2000	1592	2594	8080	2982
	Lower Leg	**Tibia Upr Left - F (N)**	1340	792	1205	815	3050	1785	1427	941	1345	2403	888	774
		Tibia Upr Right - F (N)	4218	812	1943	1878	2739	1584	2585	1513	1706	1878	2096	1290
		Tibia Lwr Left - F (N)	2561	1431	1729	1720	5002	2273	3646	2917	2519	4339	1862	1287
		Tibia Lwr Right - F (N)	5832	1640	4313	2188	3570	1601	4116	3187	2590	3642	3676	1504
		Tibia Upr Left - Rsltnt Moment (Nm)	119	98	109	88	225	54	69	116	106	101	72	86
		Tibia Upr Right - Rsltnt Moment (Nm)	125	193	144	116	97	55	116	84	101	106	158	121
		Tibia Lwr Left - Rsltnt Moment (Nm)	69	83	82	61	237	67	49	80	89	101	78	43
		Tibia Lwr Right - Rsltnt Moment (Nm)	118	178	193	58	95	54	120	101	95	153	204	91
Right Front Passenger THOR 50M	**Head**	**HIC15**	118	107	1271	220	149	108	806	946	112	197	227	114
		BrIC	1.21	1.13	1.78	1.29	0.91	1.54	1.12	1.46	0.91	1.08	1.46	0.90
	Neck	**Nij**	0.31	0.37	0.64	0.39	0.26	0.32	0.48	0.53	0.36	0.28	0.29	0.42
	Chest	**Chest Deflection (mm)**	33.1	52.3	52.7	36.5	36.0	35.6	40.1	50.4	37.9	38.0	36.2	42.6
	Abdomen	**Abdomen Deflection (mm)**	60.3	66.7	69.9	53.5	58.2	61.2	58.8	67.8	56.5	---[1]	---[1]	62.3
	KTH	**Acetabulum Force - Left (N)**	3268	2197	2437	2460	2362	1523	2425	4456	---[1]	2990	3542	2457
		Acetabulum Force - Right (N)	2287	1743	3559	2353	1730	1872	2877	2532	2812	2344	3507	2044
		Femur Force - Left (N)	3751	3626	2478	4675	4636	3521	5487	5192	3311	4021	5641	5059
		Femur Force - Right (N)	2232	2968	3916	2356	2460	4519	1877	5512	1526	3397	1372	4707
	Lower Leg	**Tibia Upr Left - F (N)**	2386	2157	1666	1344	1105	1914	2946	1656	3017	2114	2248	2894
		Tibia Upr Right - F (N)	2309	1593	1754	868	1337	1687	3099	1419	3000	2537	1415	710
		Tibia Lwr Left - F (N)	2848	2792	2231	---[1]	1518	1724	1867	1418	2262	2837	3310	3556
		Tibia Lwr Right - F (N)	3340	2453	3069	1071	1661	1405	2069	934	1973	2968	1838	446
		Tibia Upr Left - Rsltnt Moment (Nm)	181	103	89	91	91	96	130	69	140	183	132	71

		Tibia Upr Right - Rsltnt Moment (Nm)	141	73	157	130	44	105	98	41	116	99	152	116
		Tibia Lwr Left - Rsltnt Moment (Nm)	123	90	106	46	60	64	102	174	142	116	127	91
		Tibia Lwr Right - Rsltnt Moment (Nm)	121	113	146	116	64	68	106	82	148	138	151	79

[1]Questionable or lost data.

Appendix IX - Results of Driver Side MDB Fleet Testing

			2016 Chevrolet Malibu Limited	2016 Nissan Rogue	2016 Honda Fit	2016 Toyota Sienna	2016 Chevrolet Tahoe	2016 Ford F-150
		Test Number	**9787**	**9786**	**9789**	**9790**	**9788**	**9791**
Driver-WorldSID 50th	**Head**	**HIC15**	90	53	79	35	26	8
		HIC36	125	79	138	49	26	15
		BrIC	0.39	0.78	0.81	0.52	0.46	0.18
	Shoulder	**ShoulderFy (N)**	-1730	-975	-1216	-711	-1262	-360
		ShoulderRearLengthChange (mm)	20	14	5	4	18	5
		ShoulderMiddleLengthChange (mm)	32	10	12	7	18	5
		ShoulderFrontLengthChange (mm)	25	4	19	6	8	6
	Thorax	**TRib1RearLengthChange (mm)**	17	11	11	8	13	5
		TRib1MiddleLengthChange (mm)	16	9	13	10	13	4
		TRib1FrontLengthChange (mm)	12	3	9	6	9	3
		TRib2RearLengthChange (mm)	22	14	14	12	20	7
		TRib2MiddleLengthChange (mm)	23	12	15	14	19	7
		TRib2FrontLengthChange (mm)	14	8	7	9	9	4
		TRib3RearLengthChange (mm)	12	12	13	7	8	2
		TRib3MiddleLengthChange (mm)	15	11	14	9	8	2
		TRib3FrontLengthChange (mm)	10	7	7	5	5	1
		Maximum Deflection	*23*	*14*	*15*	*14*	*20*	*7*
	Abdomen	**ARib1RearLengthChange (mm)**	14	10	13	11	10	5
		ARib1MiddleLengthChange (mm)	17	12	16	12	12	5
		ARib1FrontLengthChange (mm)	10	5	9	7	5	3
		ARib2RearLengthChange (mm)	18	13	19	11	20	4
		ARib2MiddleLengthChange (mm)	20	15	22	15	22	7
		ARib2FrontLengthChange (mm)	12	11	15	10	15	6
		Maximum Deflection	*20*	*15*	*22*	*15*	*22*	*7*
	Chest	**T12Ar (G)**	36	41	35	21	33	20.
	Pelvis	**PelvisAr (G)**	35	50	46	38	51	18
		PubicFy (N)	730	1251	1334	1146	724	437
		SacroIliacLFr (N)	2020	2396	2187	1758	2289	724

Appendix X - Results of Rear Passenger Side MDB Fleet Testing

		Make and Model	2016 Chevrolet Malibu Limited	2016 Nissan Rogue	2016 Honda Fit	2016 Toyota Sienna	2016 Chevrolet Tahoe	2016 Ford F-150
		Test Number	**9787**	**9786**	**9789**	**9790**	**9788**	**9791**
Rear Passenger-SIDIIs	**Head**	**HIC15**	224	121	149	72	70	19
		HIC36	237	168	187	123	100	32
		BrIC	0.65	0.83	1.25	0.73	0.36	0.63
	Neck	**NeckUpperTension (N)**	324	159	2,216	426	146	323
		NeckUpperCompression (N)	-805	-965	-13,373[1]	-165	-486	-211
	Shoulder	**ShoulderFy (N)**	-709	-874	-1,164	-1,043	-18	-282
		ShoulderDy (mm)	14	15	33	26	0	3
	Thorax	**ThoraxRib1Dy (mm)**	23	12	32	16	8	8
		ThoraxRib2Dy (mm)	0	5	31	11	0	9
		ThoraxRib3Dy (mm)	17	7	30	3	11	7
		Maximum Deflection	*23*	*12*	*32*	*16*	*11*	*9*
	Abdomen	**AbdomenRib1Dy (mm)**	23	16	39	1	8	5
		AbdomenRib2Dy (mm)	26	18	30	3	4	5
		Maximum Deflection	*26*	*18*	*39*	*3*	*8*	*5*
	Lower Spine	**T12Ar (G)**	44	46	72	47	22	18
	Pelvis	**PelvisAr (G)**	60	50	63	45	19	46
		PelvicFy (N)	2,928	3,651	1,687	2,525	507	641

[1] Anomaly in data

Appendix XI - Results of Side Pole Fleet Testing

		Make Model	2016 Chevrolet Malibu Limited	2016 Nissan Rogue	2016 Honda Fit	2016 Toyota Sienna	2016 Chevrolet Tahoe	2016 Ford F-150
		Test Number	**9782**	**9780**	**9783**	**9785**	**9781**	**9784**
Driver-WorldSID 50th	Head	**HIC15**	476	528	202	412	349	269
		HIC36	563	623	317	469	354	374
		BrIC	0.78	0.83	0.6	0.47	0.74	0.61
	Shoulder	**ShoulderFy (N)**	-2062	-1910	-1872	-1646	-2152	-1716
		ShoulderRearLengthChange (mm)	11[2]	25[1]	10[2]	6	16	6
		ShoulderMiddleLengthChange (mm)	34[2]	40	41	26	35	23
		ShoulderFrontLengthChange (mm)	64	32	60	50	46	48
	Thorax	**TRib1RearLengthChange (mm)**	18	21	22	23	18[4]	12
		TRib1MiddleLengthChange (mm)	44	22	40	41	33[4]	39
		TRib1FrontLengthChange (mm)	61	10	41	39	37	61
		TRib2RearLengthChange (mm)	14	23	18	25	16	12
		TRib2MiddleLengthChange (mm)	29[1]	24	24[3]	32	27	33
		TRib2FrontLengthChange (mm)	28[3]	9	20[3]	22	26	46
		TRib3RearLengthChange (mm)	17	14	16	20	13	12
		TRib3MiddleLengthChange (mm)	30	16	13	19	20	17
		TRib3FrontLengthChange (mm)	26	9	9	8	17	13
		Maximum Deflection	*61*	*24*	*41*	*41*	*37*	*61*
	Abdomen	**ARib1RearLengthChange (mm)**	22	15	23	26	11	18
		ARibMiddleLengthChange (mm)	40	17	26	28	21	32
		ARib1FrontLengthChange (mm)	32	10	12	14	19	28
		ARib2RearLengthChange (mm)	29	18	27	25	14	19
		ARib2MiddleLengthChange (mm)	45	22	32	28	25	36
		ARib2FrontLengthChange (mm)	33	14	18	18	22	33
		Maximum Deflection	*45*	*22*	*32*	*28*	*25*	*36*
	Lower Spine	**T12Ar (G)**	56	47	43	44	47	51
	Pelvis	**PelvisAr (G)**	61	44	47	51	57	51
		PubicFy (N)	1172	1026	1173	1267	1514	1284
		SacroIliacLFr (N)	3591	---[5]	2488	2812	3647	2215

[1] Partial LED blockage
[2] Measurement range exceeded
[3] LED blocked from top senor
[4] LED blocked from top sensor late in event
[5] Loss in data event occurred in signal

Appendix XII - Results of Pedestrian Crashworthiness Testing

*See vehicle test reports on the docket for more details on this testing.

Headform Testing

Vehicle	Test #	Vehicle Impact Location	HIC 15
2016 Chevrolet Malibu Limited	AdultHead1612	(A,11,0)	1129
	AdultHead1613	(A,8,0)	774
	AdultHead1614	(A,8,+5)	761
	AdultHead1615	(A,9,-7)	1470
	ChildHead1616	(C,0,0)	1203
	ChildHead1624	(C,3,0)	376
	ChildHead1625	(C,7,-6)	864
	ChildHead1626	(C,2,-5)	768
	ChildHead1627	(C,5,+5)	703
	ChildHead1628	(C,4,+2)	397
	ChildHead1629	(C,3,+6)	1107
2016 Honda Fit	ChildHead1617	(C,0,0)	624
	ChildHead1618	(C,3,+6)	724
	ChildHead1619	(C,4,-6)	1223
	ChildHead1620	(C,4,0)	658
	ChildHead1621	(C,1,-6)	1053
	ChildHead1622	(C,2,+7)	1224
	AdultHead1623	(A,8,-5)	483
	ChildHead1630	(C,3,+3)	431
	ChildHead1631	(C,2,-2)	380
2016 Nissan Rogue	AdultHead1601	(A,11,0)	572
	AdultHead1602	(A,8,0)	563
	AdultHead1603	(A,8,-5)	715
	AdultHead1604	(A,9,+7)	1096
	ChildHead1605	(C,0,0)	1199
	ChildHead1606	(C,1,-4)	1574
	ChildHead1607	(C,6,-2)	423
	ChildHead1608	(C,6,+7)	532
	ChildHead1609	(C,3,-7)	1074
	ChildHead1610	(C,4,0)	566
	ChildHead1611	(C,4,+5)	690
2015 Toyota Sienna	AdultHead1643	(A,9,0)	692
	ChildHead1644	(C,5,0)	655
	ChildHead1645	(C,0,0)	909
	ChildHead1646	(C,6,-7)	1209
	ChildHead1647	(C,4,-4)	596
	ChildHead1648	(C,1,+3)	839
	ChildHead1649	(C,3,+7)	1319
	ChildHead1650	(C,2,0)	705
	ChildHead1651	(C,3,-6)	1250
2016 Chevrolet Tahoe	ChildHead1632	(C,7,0)	506
	ChildHead1633	(C,7,-7)	764
	ChildHead1634	(C,2,0)	2320
	AdultHead1635	(A,10,+5)	979
	AdultHead1636	(A,11,0)	615
	AdultHead1637	(A,9,+2)	398
	AdultHead1638	(A,12,-7)	1502
	ChildHead1639	(C,6,-3)	611
	ChildHead1640	(C, 3,+3)	1622
	ChildHead1641	(C,5,+8)	2122
	AdultHead1642	(A,9,-7)	1050
2015 Ford F-150	ChildHead1501	(C,5,0)	1070
	ChildHead1502	(C,4,+7)	1466
	ChildHead1503	(C,3,-5)	1244
	AdultHead1504	(A,13,-8)	2576
	AdultHead1505	(A,11,0)	999
	AdultHead1506	(A,11,+8)	1198
	ChildHead1507	(C,3,-3)	1121
	ChildHead1508	(C,6,-8)	3163
	ChildHead1509	(C,2,0)	1862
	AdultHead1510	(A,8,-5)	1043
	AdultHead1511	(A,10,+4)	575

Lower Legform (Flex-PLI) Testing

Vehicle	Test #	Vehicle Impact Location	Tibia 1 Bending Moment (Nm)	Tibia 2 Bending Moment (Nm)	Tibia 3 Bending Moment (Nm)	Tibia 4 Bending Moment (Nm)	MCL Elongation (mm)	ACL Elongation (mm)	PCL Elongation (mm)
2016 Chevrolet Malibu Limited	LL 1607	L+1	302	411	258	126	14.1	6.9	5.2
	LL 1608	L+5	376	296	185	105	20.9	9.6	9.6
	LL 1609	L-7	403	351	239	121	25.1	9.4	8.1
	LL 1610	L-3	319	346	215	116	13.6	6.1	4.4
2016 Honda Fit	LL 1602	L-5	394	325	218	152	21.6	15.9	8.2
	LL 1603	L+3	469	401	241	130	26.2	15.9	7.2
	LL 1604	L-1	435	391	259	119	27.9	15.6	7.5
2016 Nissan Rogue	LL 1605	L-5	150	173	177	99	14.2	7.5	4.3
	LL 1606	L+3	254	246	244	128	11.2	7.0	3.7
	LL 1611	L-1	207	211	207	116	9.8	6.9	4.5
2015 Toyota Sienna	LL 1612	L-5	389	349	250	125	29.9	11.5	8.3
	LL 1613	L+3	375	327	247	147	31.0	11.6	8.2
	LL 1614	L+7	421	363	248	112	28.5	14.2	8.7
	LL 1615	L-1	374	342	242	146	29.1	11.0	9.5
2016 Chevrolet Tahoe	LL 1616	L+1	383	367	272	115	29.7	10.3	13.7
	LL 1617	L-5	354	360	275	119	26.1	8.3	3.8
	LL 1618	L-3	374	358	255	109	29.0	10.2	16.1
2015 Ford F-150	FlexPLI1501	(L,0)	354	308	199	96	32.8	11.7	9.3
	FlexPLI1502	(L,+2)	370	312	204	86	34.1	12.1	9.1
	FlexPLI1503	(L,-4)	394	336	211	85	34.3	13.3	9.4

Upper Legform Testing

Vehicle	Test #	Vehicle Impact Location	Impact Angle (deg)	Impact Energy (J)	Upper Bending Moment (Nm)	Middle Bending Moment (Nm)	Lower Bending Moment (Nm)	Sum of Upper & Lower Forces (N)
2016 Chevrolet Malibu Limited	UL 1605	U+1	28.5	312	249	220	153	5663
	UL 1606	U-3	31.2	288	220	212	166	5304
	UL 1607	U+5	38.1	223	275	313	269	5066
	UL 1608	U-7	36.2	241	210	225	174	3777
2016 Honda Fit	UL 1601	U-1	39.0	214	132	150	128	2757
	UL 1602	U+3	38.9	215	193	231	204	3531
	UL 1603	U-5	40.7	198	227	245	195	4585
2016 Nissan Rogue	UL 1610	U+3	19.1	387	104	104	91	4373
	UL 1611	U-1	16.8	402	148	171	147	4421
	UL 1612	U-5	22.1	366	182	200	168	4239
	UL 1613	U+7	24.1	350	148	153	128	3518
2016 Toyota Sienna	UL 1614	U+3	26	334	224	229	185	5861
	UL 1615	U-1	22.6	362	257	267	210	5969
	UL 1616	U-5	28.3	315	194	197	158	5154
	UL 1617	U+7	25	343	135	137	114	3877
2016 Chevrolet Tahoe	UL 1651	U+3	8.5	442	88	118	145	8739
	UL 1652	U-1	8.4	443	71	83	96	7341
	UL 1653	U-5	9.4	439	131	173	202	10479
	UL 1654	U+7	10.9	433	201	216	178	3765
2015 Ford F-150	UL 1647	U+7	7.3	446	115	164	149	7927
	UL 1648	U-5	5.6	450	39	60	64	7549
	UL 1649	U-3	4.5	453	85	95	83	7786
	UL 1650	U+1	4.2	453	116	119	98	4785

Appendix XIII – Driver Comparison of Validation and NCAP Fleet Testing

Table 1. Driver Comparison of WorldSID-50M Validation MDB Testing and ES-2re NCAP Fleet MDB Testing

Vehicle Make		CHEVROLET		NISSAN		HONDA		TOYOTA		CHEVROLET		FORD	
Vehicle Model		MALIBU LIMITED		ROGUE		FIT		SIENNA		TAHOE		F150	
Vehicle Model Year		2016	2014	2016	2014	2016	2015	2015	2015	2016	2015	2016	2015
Test Number		9787	8485	9786	8546	9789	9036	9790	9015	9788	8642	9791	9087
Occupant & Location		01 WS50M	01 ES-2re	01 WS50M	01 ES-2re	01 WS50M	01 ES-2re	01 WS50M	01 ES-2re	01 WS50M	01 ES-2re	01 WS50M	01 ES-2re
Head	HIC15	90	121	53	34	79	130	35	26	26	11	8	16
	BRIC	0.39	n/a	0.78	n/a	0.81	n/a	0.52	n/a	0.46	n/a	0.18	n/a
Thorax	Maximum Deflection	23	25	14	26	15	25	14	14	20	17	7	17
Abdomen	Maximum Deflection	20	n/a	15	n/a	22	n/a	15	n/a	22	n/a	7	n/a
	Combined Abdomen	n/a	757	n/a	899	n/a	965	n/a	641	n/a	474	n/a	317
Lower Spine	T12Ar (G)	36	27	41	35	35	36	21	21	33	---[1]	20	18
Pelvis	PubicFy (N)	730	1365	1251	2120	1334	1738	1146	1738	724	951	437	721
	SacroIliacLFr (N)	2020	n/a	2396	n/a	2187	n/a	1758	n/a	2289	n/a	723	n/a

[1] Invalid data

Table 2. Driver Comparison of WorldSID-50M and ES-2re Validation Pole Testing and SID-IIs NCAP Fleet Pole Testing

Vehicle Make		CHEVROLET			NISSAN			HONDA		
Vehicle Model		MALIBU LIMITED			ROGUE			FIT		
Vehicle Model Year		2016	2016	2014	2016	---	2014	2016	2016	2015
Test Number		9782	9948	8471	9780	---	8544	9783	9949	9034
Occupant & Location		01 WS50M	01 ES-2re	01 SID-IIs	01 WS50M	01 ES-2re	01 SID-IIs	01 WS50M	01 ES-2re	01 SID-IIs
Head	HIC15	476	457	347	528	---	529	202	422	230
	BRIC	0.78	n/a	n/a	0.83	---	n/a	0.60	n/a	n/a
Thorax	Maximum Deflection	61	27	21	24	---	28	41	29	21
Abdomen	Maximum Deflection	45	n/a	15	22	---	17	32	n/a	19
	Combined Abdomen	n/a	1036	n/a	n/a	---	n/a	n/a	1028	n/a
Lower Spine	T12Ar (G)	56	57[1]	44	47	---	38	43	45	37
Pelvis	PubicFy (N)	1172	3097	n/a	1026	---	n/a	1173	1680	n/a
	Combined Pelvis (N)	n/a	n/a	2267	n/a	---	3486	n/a	n/a	2837
	SacroIliacLFr (N)	3591	n/a	n/a	---[1]	---	n/a	2488	n/a	n/a
Vehicle Make		TOYOTA			CHEVROLET			FORD		
Vehicle Model		SIENNA			TAHOE			F150		
Vehicle Model Year		2016	---	2015	2016	---	2015	2016	2016	2015
Test Number		9785	---	9014	9781	---	8640	9784	9950	9088
Occupant & Location		01 WS50M	01 ES-2re	01 SID-IIs	01 WS50M	01 ES-2re	01 SID-IIs	01 WS50M	01 ES-2re	01 SID-IIs
Head	HIC15	412	---	331	349	---	307	269	234	185
	BRIC	0.47	---	n/a	0.74	---	n/a	0.61	n/a	n/a
Thorax	Maximum Deflection	41	---	16	37	---	23	61	39	19
Abdomen	Maximum Deflection	28	---	16	25	---	24	36	n/a	17
	Combined Abdomen	n/a	---	n/a	n/a	---	n/a	n/a	1436	n/a
Lower Spine	T12Ar (G)	44	---	33	47	---	50	51	56	46
Pelvis	PubicFy (N)	1267	---	n/a	1514	---	n/a	1284	2214	n/a
	Combined Pelvis (N)	n/a	---	2608			3972	n/a	n/a	2059
	SacroIliacLFr (N)	2812	---	n/a	3647	---	n/a	2215	n/a	n/a

[1] Questionable data

Appendix XIV – Crash Avoidance

Crash Avoidance System	Crash Typology Pre-Crash Scenario (Light-vehicle crashes)	Target Population	Estimated System Effectiveness	Crash Avoidance Safety Improvement Potential	
Amber Rear Turn Signal Lamps	• Lead vehicle stopped • Lead vehicle decelerating • Lead vehicle moving at lower constant speed • Following vehicle making a maneuver • Vehicle changing lanes - same direction • Vehicle turning - same direction • Vehicle parking - same direction	16,650 (MAIS 1-5) injuries[1]	5.3 percent effective at preventing involvement as a rear-struck vehicle in a turn-related collision[2]	0 fatalities prevented	882 injuries prevented[3]
Blind Spot Detection	• Vehicle changing lanes - same direction • Vehicle turning - same direction • Vehicle drifting - same direction • Vehicle parking - same direction	Estimates vary: 146 fatalities[4] 393 fatalities[5] 428 fatalities[6] 510 fatalities[7] Estimates vary: 4,700 injuries[4] 20,000 injuries[5] 24,000 (MAIS 3+) injuries[6] 133,212 (MAIS 1-5) injuries[8]	Prevent 1 – 3 percent of crashes[9] 11 percent[16] (ACAT II simulation: 42%-65%)[4] [cf: 5.90% (Large Truck Crash Causation Study)]	5 fatalities[10] (61-95 fatalities)[4]	1,332 injuries[10] (2,000-3,000 injuries)[4]
FCW	• Lead vehicle stopped • Lead vehicle decelerating • Lead vehicle moving at lower constant speed • Following vehicle making a maneuver • Lead vehicle accelerating • Object crash with prior vehicle maneuver • Object crash without prior vehicle maneuver	746 fatal front-rear crashes[6] 1,148 fatalities[7] 67,000 nonfatal front-rear injury crashes[6] 852,812 (MAIS 1-5) injuries[8] (more crash types	15% in reducing rear-end crashes[11] 10% in reducing rear-end crashes[13, 9] 12% reduction in fatalities[17] 23 percent[16] 30 percent reduction rear-end crashes[25] (simulation) 38% in reducing rear-end crashes[14, 24] prevented 3.2% of rear-end crashes[22] prevent 29% of AIS 2+ injuries[22] [cf: 23.8% (Large Truck Crash Causation Study)]	35 fatalities[12]	1,260 (AIS3+ injuries) [12]

		than just front-rear)			
CIB	• Lead vehicle stopped • Lead vehicle decelerating • Lead vehicle moving at lower constant speed • Following vehicle making a maneuver • Lead vehicle accelerating • Object crash without prior vehicle maneuver	746 fatal front-rear crashes[6] 1,394 fatal crashes[18] 67,000 nonfatal front-rear injury crashes[6] 31,000 (MAIS 3+) nonfatal injury crashes[18]	FCW + CIB + DBS = 29 to 41 percent[15, 19] Consider FCW = 10 percent, then CIB + DBS = 19 percent. Estimate CIB as [40/(40+25)] x (0.19) = 12 percent	40 fatalities[15]	640 (AIS3+ injuries)[15]
DBS	• Lead vehicle stopped • Lead vehicle decelerating • Lead vehicle moving at lower constant speed • Following vehicle making a maneuver • Lead vehicle accelerating • Object crash without prior vehicle maneuver	746 fatal front-rear crashes[6] 1,394 fatal crashes[18] 67,000 nonfatal front-rear injury crashes[6] 31,000 (MAIS 3+) nonfatal injury crashes[18]	FCW + CIB + DBS = 29 percent[15, 19] Consider FCW = 10 percent, then CIB + DBS = 19 percent. Estimate DBS as [25/(40+25)] x (0.19) = 7 percent	25 fatalities[15]	2,100 (AIS3+ injuries)[15]
Lower Beam Headlighting Performance	• Vehicle turning at non-signalized junctions • Left turn across path/opposite direction at signalized junction • Left turn across path/opposite direction at non-signalized junction • Running stop sign • Vehicle turning right at signalized junctions • Road edge departure without prior vehicle maneuver • Road edge departure with prior vehicle maneuver • Evasive action with prior vehicle maneuver • Evasive action without prior vehicle maneuver • Animal crash without prior vehicle maneuver	13,876 fatalities[7] 8,600 fatalities[29] (reduce this number to remove low speed crashes < 25 mph addressed by PAEB systems) 436,025 (MAIS 1-5) injuries[8] (reduce this number to remove low speed crashes < 25 mph addressed by PAEB systems)	10 percent[16] for both headlighting systems (split 8% for Lower Beam and 2% for beam switching)[33]	240 fatalities[29]	10,000 injuries[33]

	• Animal crash with prior vehicle maneuver • Pedestrian crash with prior vehicle maneuver • Pedestrian crash without prior vehicle maneuver • Pedalcyclist crash with prior vehicle maneuver • Pedalcyclist crash without prior vehicle maneuver • Object crash with prior vehicle maneuver • Object crash without prior vehicle maneuver				
Semi-automatic Headlamp Beam Switching	• Running stop sign • Road edge departure without prior vehicle maneuver • Road edge departure with prior vehicle maneuver • Evasive action with prior vehicle maneuver • Evasive action without prior vehicle maneuver • Animal crash without prior vehicle maneuver • Animal crash with prior vehicle maneuver • Pedestrian crash with prior vehicle maneuver • Pedestrian crash without prior vehicle maneuver • Pedalcyclist crash with prior vehicle maneuver • Pedalcyclist crash without prior vehicle maneuver • Object crash with prior vehicle maneuver Object crash without prior vehicle maneuver	13,876 fatalities[7] (reduce this number to remove low speed crashes < 35 mph where the beam switching systems are not engaged and <25 mph addressed by PAEB systems.) 436,025 (MAIS 1-5) injuries[8] (adjust/reduce this number to remove low speed crashes < 35mph where the beam switching systems are not engaged and <25 mph addressed by PAEB systems.)	10 percent[16] for both headlighting systems (split 8% for Lower Beam and 2% for beam switching)[33]	60 fatalities[29]	2,000 injuries[33]

LDW	• Road edge departure/no maneuver • Opposite direction/no maneuver • Drifting/same lane • Object contacted/no maneuver	10,801 fatalities[7] 10,345 fatal front-rear crashes[6] 7,529 fatal crashes[5] 346,222 (MAIS 1-5) injuries[8] 87,000 (MAIS 3+) nonfatal injury crashes[6] 37,000 injuries[5]	Prevent 4-15% crashes[9] 3 percent[16] 6% reduction in fatalities[17] 7% reduction in lane departures[21] 6-34% reduction in lane departures[22] 13% to 31% in reducing lane-departure crashes[26] 7%-29% of fatalities[27] 13%-34% of serious injuries[27] 13%-35% of minor injuries[27] 11%-13% fatal crashes[28] 2% to 9% injury crashes[28]	131 fatalities[31]	3,280 injuries[31]
Rollover Resistance	• Road edge departure without prior vehicle maneuver • Evasive action with prior vehicle maneuver • Evasive action without prior vehicle maneuver	6,763 occupant fatalities[30] 22,933 (MAIS 1-5) injuries[8]	31 percent reduction in fatalities for the number of accidents in which rollovers would be prevented;[20] 55 percent reduction in serious injuries (AIS 3+) for the number of accidents in which rollovers would be prevented[20]	101 fatalities[32]	344 injuries[32]
			Total	637 fatalities	21,838 injuries

[1] Target population calculated as the number of MAIS 1-5 injuries reported in non-fatal, two-vehicle, rear-end crashes where the lead vehicle is changing direction (NHTSA GES 2009 – 2011 data) multiplied by 54%, the volume-based percent of vehicles with red turn signals.

[2] DOT HS 811 115, April 2009; NHTSA's State Data System: 14 states with data ranging in years between 1981 and 2005.

[3] Safety improvement potential calculated as the target population multiplied time the system effectiveness. 16650 x 0.053 = 882

[4] Annualized target population of pedestrians injured in motor vehicle traffic crashes (NHTSA GES 2003 – 2007 adjusted data). Note: Effectiveness and safety improvement potential estimates for a generic sensor. Advanced Crash Avoidance Technologies (ACAT) II simulation performed by Nissan and UMTRI.

[5] Insurance Institute for Highway Safety (IIHS) Status Report, Vol. 45, No. 5, May 20, 2010.

[6] Farmer, Charles M., Crash Avoidance Potential of Five Vehicle Technologies, Insurance Institute for Highway Safety, June 2008.

[7] Annualized target population of fatalities in motor vehicle traffic crashes (NHTSA FARS 2010 – 2014 data).

[8] Annualized target population of injuries in motor vehicle traffic crashes (NHTSA GES 2010 – 2014 adjusted data).

[9] Gottselig, B., et al; "Developments of road safety trends – identification of the potential effectiveness of modern safety systems using an integrated approach." Presented at the VDA Technical Congress, Ludwigsburg, Germany, April 2-3, 2008.

[10] Conservatively chose effectiveness of 1% and multiplied by the 510 fatalities listed in NCSA target population. Similarly, injuries calculated as: 133,212 injuries listed in NCSA multiplied by 1% = 1,332 injuries safety improvement potential.

[11] 73 FR 40033.

[12] Forward-Looking Advanced Braking Technologies Research Report, NHTSA, June 2012. *www.regulations.gov* Docket No. NHTSA-2012-0057-0001.

[13] Najm, W.G.; Stearns, M.D.; Howarth, H.; Koopmann, J.; and Hitz, J. 2006. Evaluation of an automotive rear-end collision avoidance system. Report no. DOT HS-810-569. Washington, DC: National Highway Traffic Safety Administration.

[14] Sugimoto, Y. and Sauer, C. 2005. Effectiveness estimation method for advanced driver assistance system and its application to collision mitigation brake system. Paper no. 05-0148. Proceedings of the 19th International Technical Conference on the Enhanced Safety of Vehicles. Washington, DC: National Highway Traffic Safety Administration.

[15] Automatic Emergency Braking System (AEB) Research Report, An Update of the June 2012 Research Report Titled, "Forward-Looking Advanced Braking Technologies Research Report," August 2014. *www.regulations.gov* Docket No. NHTSA-2012-0057-0037, page 16. Note: assumes individual system functionality is installed on all light vehicles without other AEB systems.

[16] GM comment to the December 16, 2015 NCAP RFC; *www.regulations.gov* Docket No. NHTSA-2015-0119-0330, Appendix 7.

[17] Analysis of crash data to estimate the benefits of emerging vehicle technology. Centre for Automotive Safety Research; CASR094, April 2011.

[18] Farmer, Charles M., Crash Avoidance Potential of Five Vehicle Technologies, Insurance Institute for Highway Safety, June 2008. Table 4, Front-to-rear plus Single-driver values.

[19] Forward-Looking Advanced Braking Technologies Research Report. Washington, DC: National Highway Traffic Safety Administration (NHTSA, DOT). June 2012. www.regulations.gov Docket No. NHTSA-2012-0057-0001, page 27.

[20] Resultant values for an updated analysis of table 7 from "Potential Reductions in Fatalities and Injuries in Single Vehicle Rollover Crashes as a Result of a Minimum Rollover Stability Standard" (NHTSA Docket No. 91-068-N03) using 2015 FARS data..

[21] Sayer, J. et al., Integrated Vehicle-Based Safety System Field Operational Test Final Program Report. DOT HS 811 482. June 2011. Available at http://ntl.bts.gov/lib/45000/45600/45603/FHWA-JPO-11-150_IVBSS_Final_Program_Report_FINAL_508.PDF.pdf

[22] Blower, D., Assessment of the Effectiveness of Advanced Collision Avoidance Technologies. UMTRI-2014-3. January 2014. Available at https://deepblue.lib.umich.edu/bitstream/handle/2027.42/102534/102987.pdf?sequence=1

[23] Kusano, K. D. and H. C. Gabler (2012). "Safety Benefits of Forward Collision Warning, Brake Assist, and Autonomous Braking Systems in Rear-End Collisions." IEEE Transactions on Intelligent Transportation Systems 13(4): 1546-1555.

[24] Georgi, A., M. Zimmermann, et al. (2009). New Approach of Accident Benefit Analysis for Rear End Collision Avoidance and Mitigation Systems. 21st International Technical Conference on the Enhanced Safety of Vehicles., Stuttgart, Germany. (evaluation of a Bosch FCAT system.)

[25] Yasuda, H., A. Kozato, et al. (2011). A Forward Collision Warning (FCW) Performance Evaluation. 22nd International Technical Conference on the Enhanced Safety of Vehicles. Washington, DC.

[26] Gordon, T., H. Sardar, et al. (2010). Advanced Crash Avoidance Technologies (ACAT) Program – Final Report of the Volvo-Ford-UMTRI Project: Safety Impact Methodology for Lane Departure Warning – Method Development and Estimation of Benefits. Washington, DC: 218.

[27] Robinson, B., W. Hulshof, et al. (2011). Cost Benefit Evaluation of Advanced Primary Safety Systems, Transport Research Laboratory: 74.

[28] Anderson, R. W. G., T. P. Hutchinson, et al. (2011). Analysis of crash data to estimate the benefits of emerging vehicle technology. Adelaide, Australia, Centre for Automotive Safety Research, The University of Adelaide.

[29] Flannagan, Michael J., C. Flanigan. (June 2005). Development of a Headlighting Rating System. Working Paper No. GRE-gtr-8-5 (8th GRE-gtr informal meeting, Washington, DC, 31 May – 2 June 2005). Available at http://www.unece.org/fileadmin/DAM/trans/doc/2005/wp29gre/gtr8-5e.pdf . See Figure 2. (Headlighting safety improvement potential estimate is reduced by the safety improvement potential value of posted speed limit up to 25mph; the lives for posted speed limit up to 25mph are counted in the PAEB safety improvement potential.) Proportioned 300 fatalities as 8% x 300 = 240 to lower beam headlighting and 2% x 300 = 60 to beam switching.

[30] 2012 FARS; 1st NCAP RFC notice. Single, light vehicle rollovers.

[31] Integrated Vehicle-Based Safety Systems (IVBSS) (DOT HS 811 516) and Field Operational Test (FOT) (DOT HS 812 247) showed high percentage of LDW warning systems turned off (38% to 71% off). NCAP potential safety improvement calculated as 7529 fatalities target population x 29% systems operational x 6% effectiveness = 131 lives, and 87,000 (MAIS 3+) x 29% systems operational x 13% effectiveness = 3280 injuries

[32] Safety improvement potential calculated for rollovers that occur when ESC-equipped single-vehicles do not remain on the road if its speed is too great for the available traction and the maneuver the driver is attempting, Using the rollover risk curve generated from a logistic regression of available 2011 and 2012 State

data described in the 1st RFC notice, and the shift of the intersection points of the average SSF values for passenger cars reported in Kahane, C. J. (2015, January). Lives saved by vehicle safety technologies and associated Federal Motor Vehicle Safety Standards, 1960 to 2012 – Passenger cars and LTVs – With reviews of 26 FMVSS and the effectiveness of their associated safety technologies in reducing fatalities, injuries, and crashes. (Report No. DOT HS 812 069). Washington, DC: National Highway Traffic Safety Administration. Fatality safety improvement potential calculated as 6,763 x 0.015 = 101. Injury safety improvement potential calculated as 22,933 x 0.015 = 344.

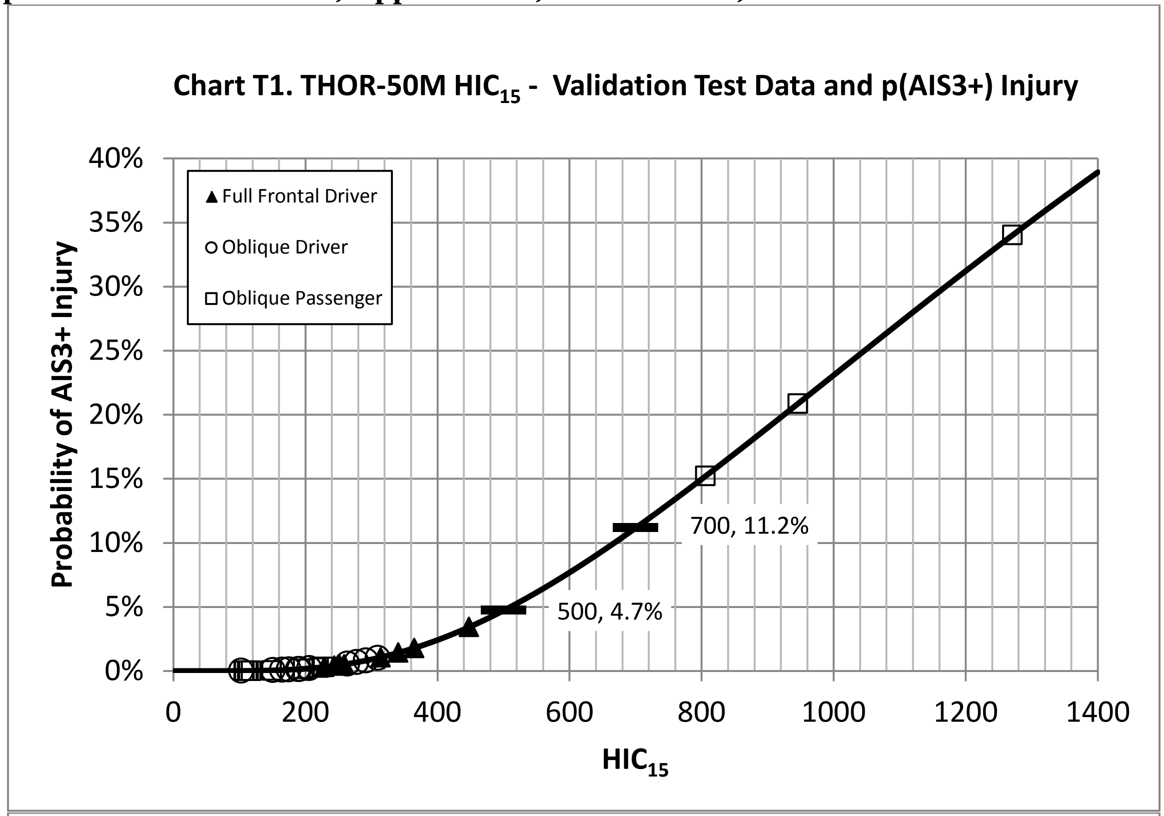
[33] NHTSA Office of Crash Avoidance Standards engineering analysis.

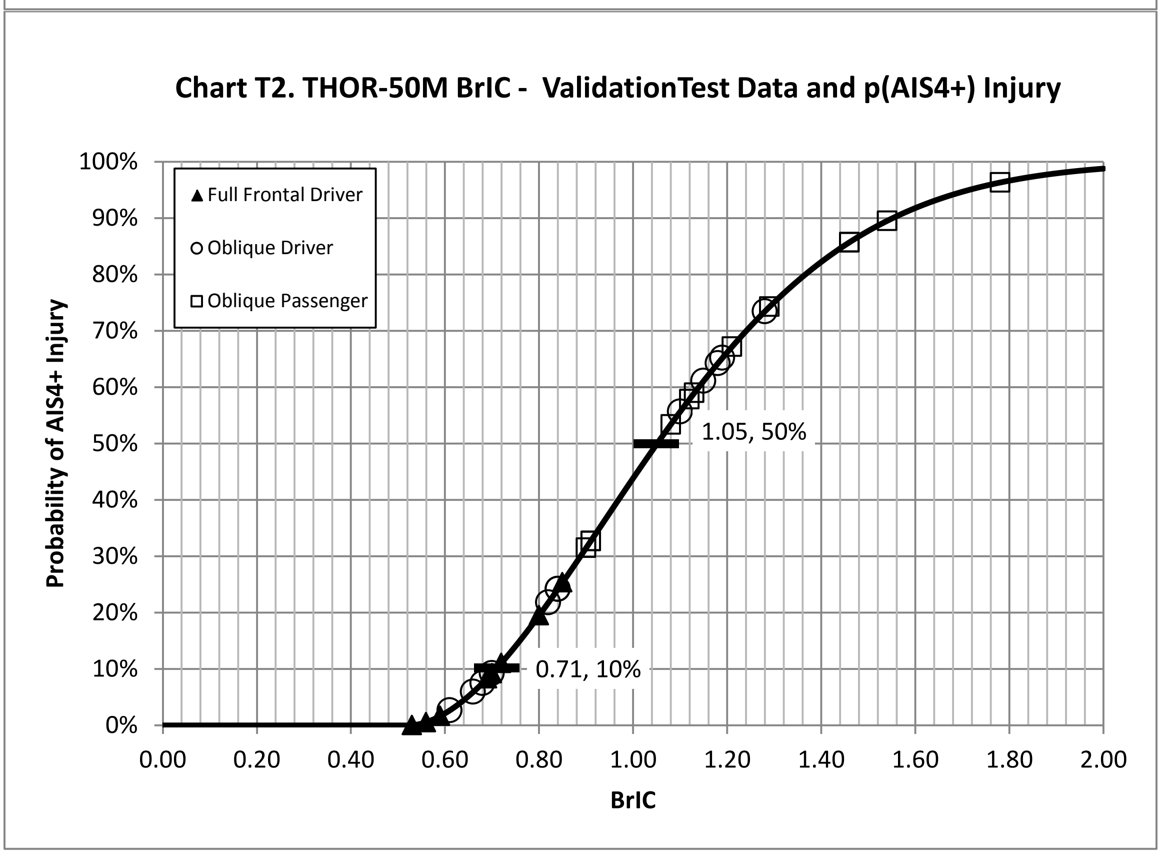
Table XIV-1 lists the crash avoidance scoring values initially published in the December 16, 2015, notice and the revised crash avoidance scoring values presented in this notice.

Table XIV-1. Crash Avoidance System Maximum Score Values

Crash Avoidance System	Scoring Values Published in the NCAP 1st RFC Notice December 16, 2015	Revised Scoring Values Published in the NCAP 2nd RFC Notice
FCW	12 points	10 percent
CIB	12 points	12 percent
DBS	11 points	8 percent
Lower beam headlighting distance	15 points	20 percent
Semi-automatic headlamp beam switching	9 points	10 percent
Amber rear turn signal lamps	6 points	5 percent
LDW	7 points	12 percent
Rollover Resistance	20 points	18 percent
Blind Spot Detection	8 points	5 percent
Total	100 points	100 percent

Appendix XV: Risk Curves, Upper Limits, Lower Limits, and Validation Data





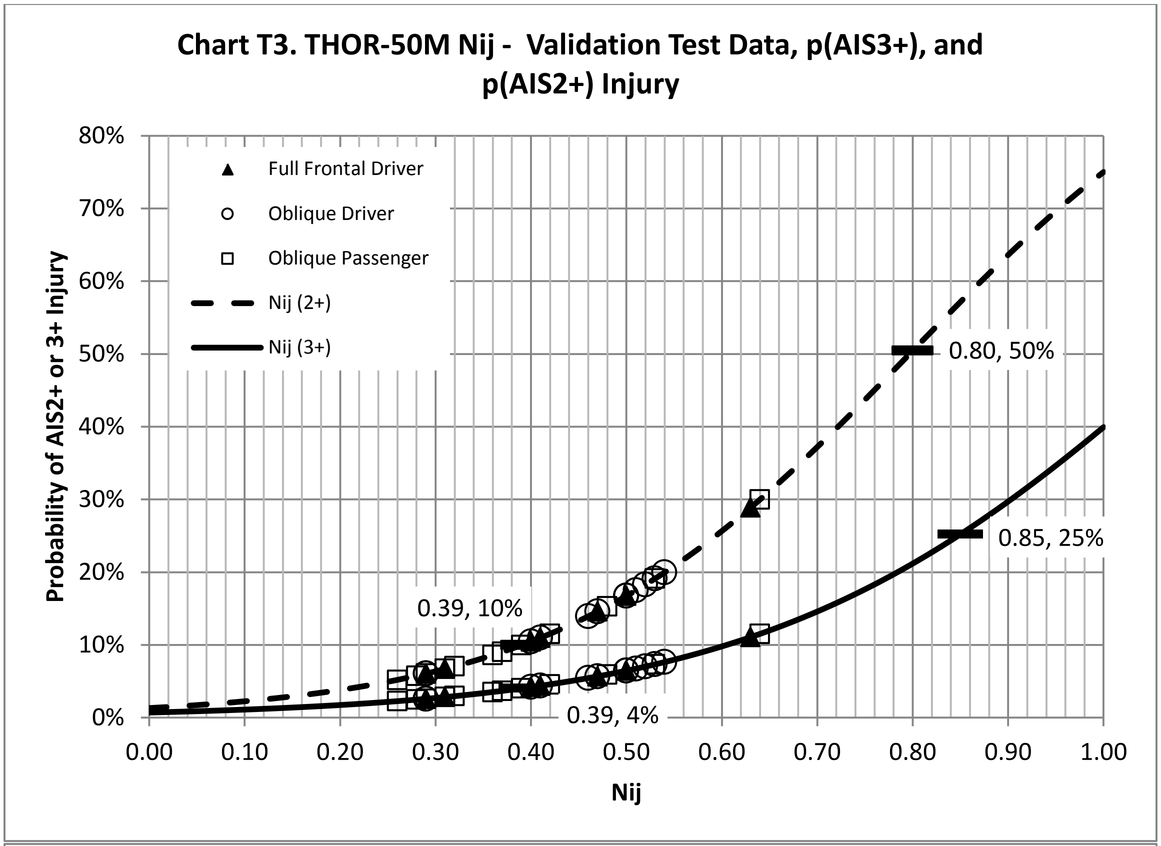


Chart T3. THOR-50M Nij - Validation Test Data, p(AIS3+), and p(AIS2+) Injury
Full Frontal Driver
Oblique Driver
Oblique Passenger
Nij (2+)
Nij (3+)
0.80, 50%
0.85, 25%
0.39, 10%
0.39, 4%
Probability of AIS2+ or 3+ Injury
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Nij

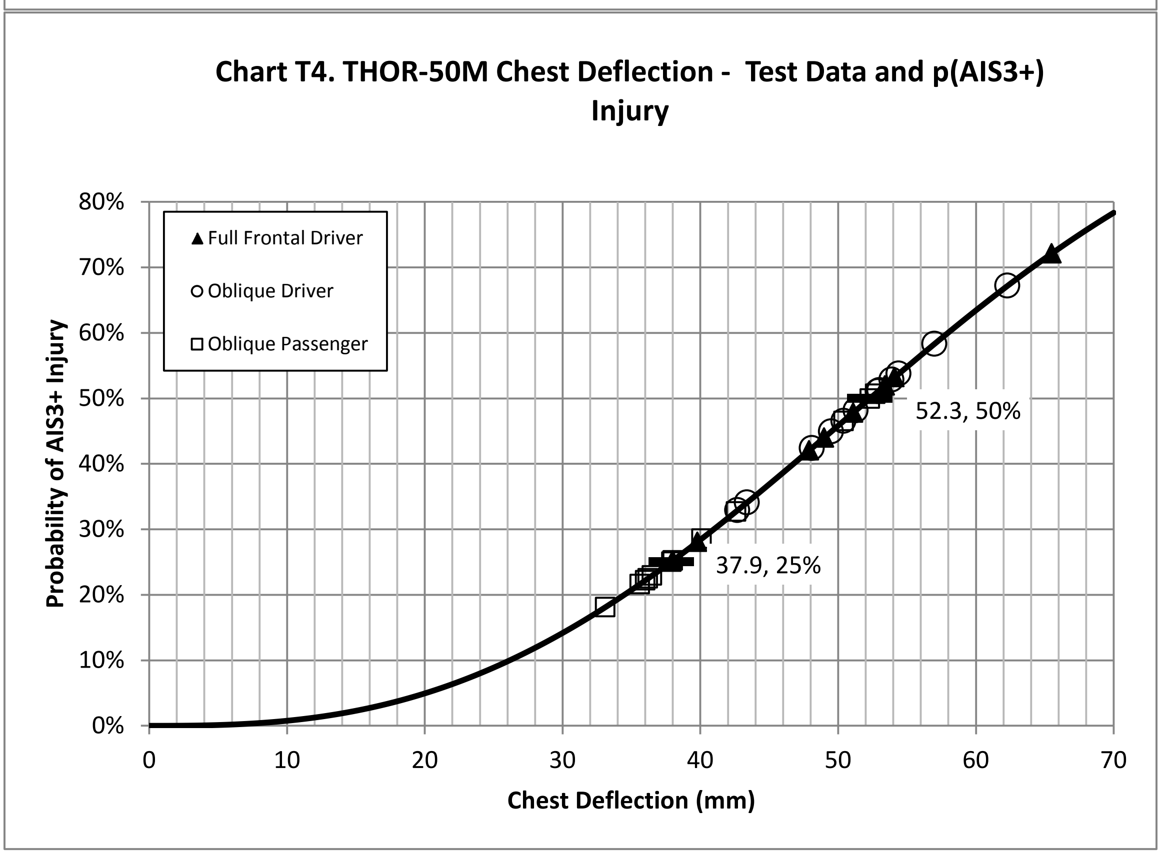


Chart T4. THOR-50M Chest Deflection - Test Data and p(AIS3+) Injury
Full Frontal Driver
Oblique Driver
Oblique Passenger
52.3, 50%
37.9, 25%
Probability of AIS3+ Injury
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
10
20
30
40
50
60
70
Chest Deflection (mm)

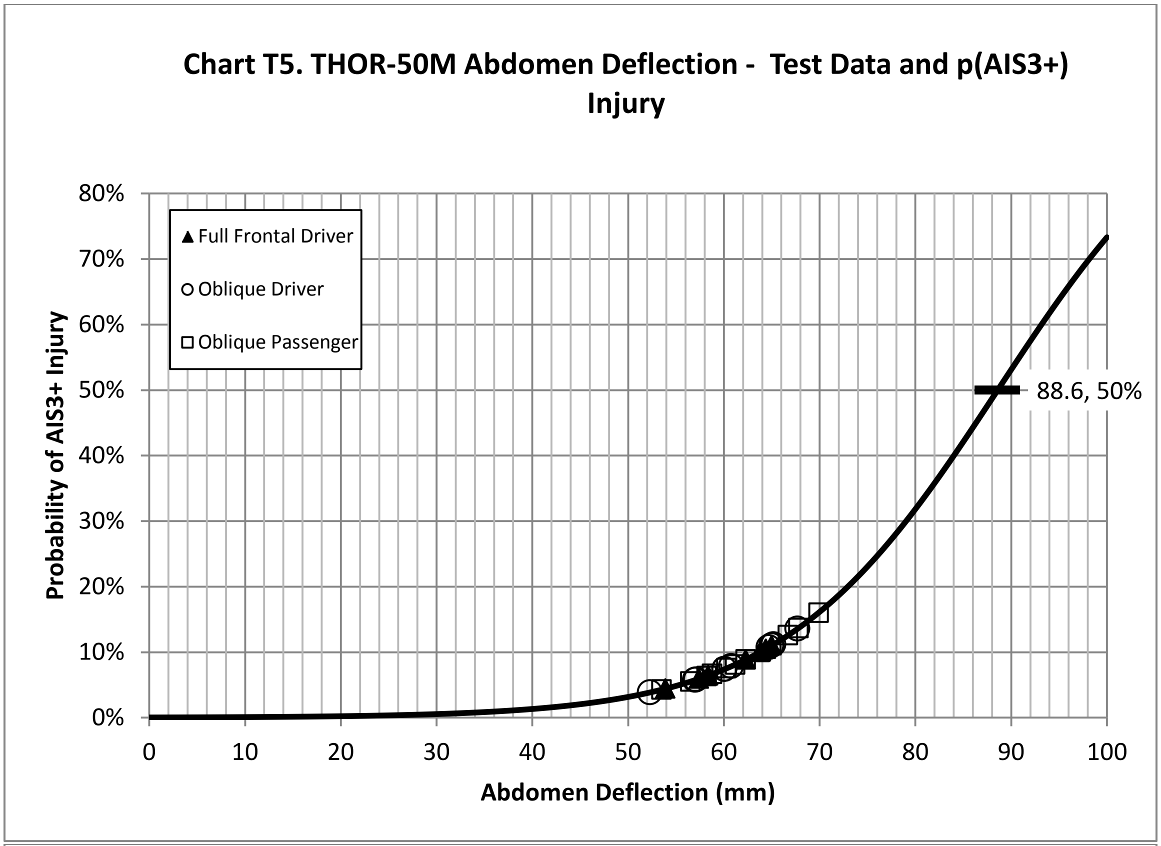


Chart T5. THOR-50M Abdomen Deflection - Test Data and p(AIS3+) Injury
Full Frontal Driver
Oblique Driver
Oblique Passenger
88.6, 50%
Probability of AIS3+ Injury
Abdomen Deflection (mm)
0%
10%
20%
30%
40%
50%
60%
70%
80%
0
10
20
30
40
50
60
70
80
90
100

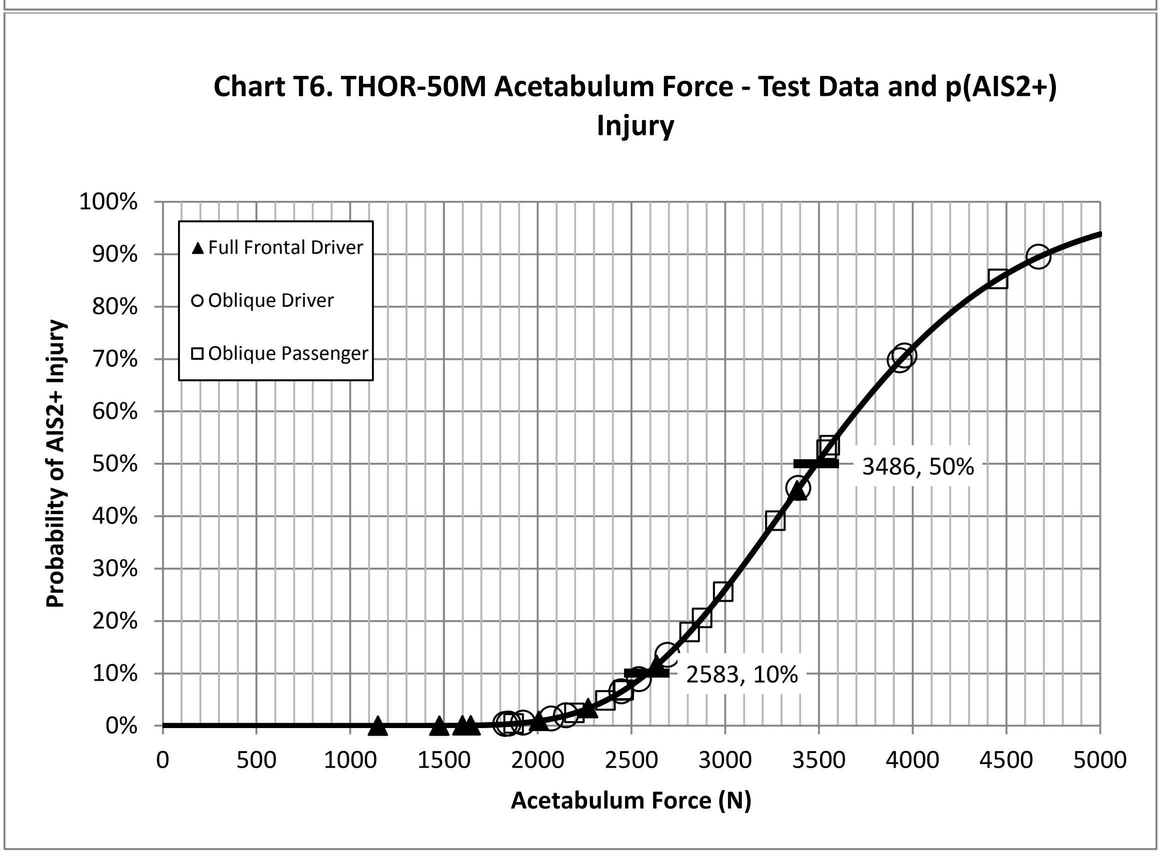


Chart T6. THOR-50M Acetabulum Force - Test Data and p(AIS2+) Injury
Full Frontal Driver
Oblique Driver
Oblique Passenger
3486, 50%
2583, 10%
Probability of AIS2+ Injury
Acetabulum Force (N)
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000

Chart T7. THOR-50M Femur Force - Test Data and p(AIS2+) Injury

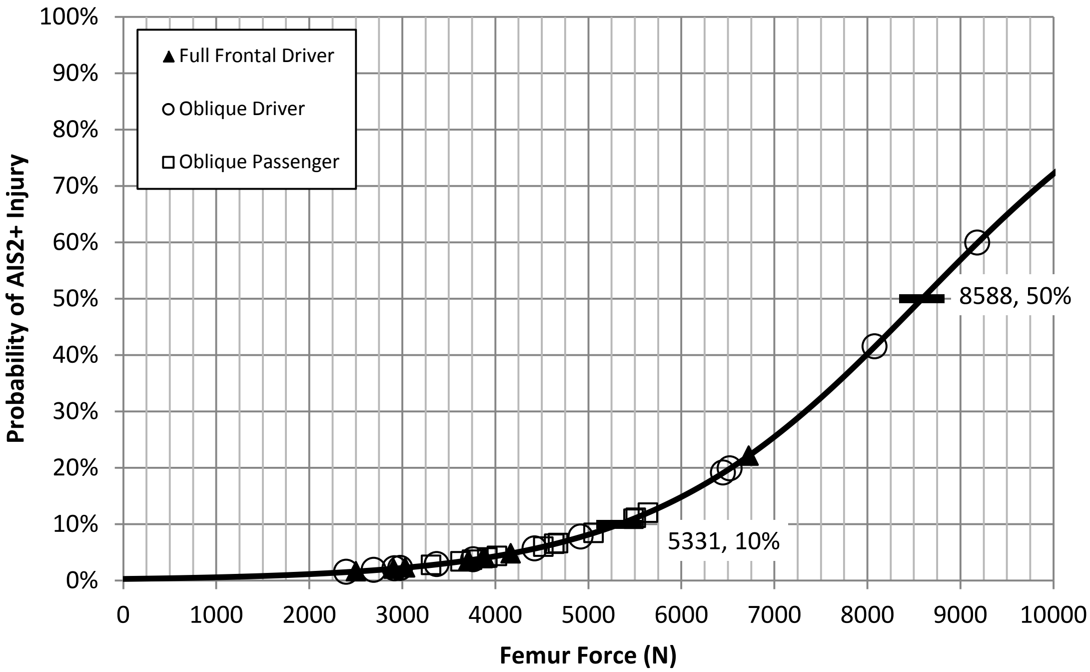
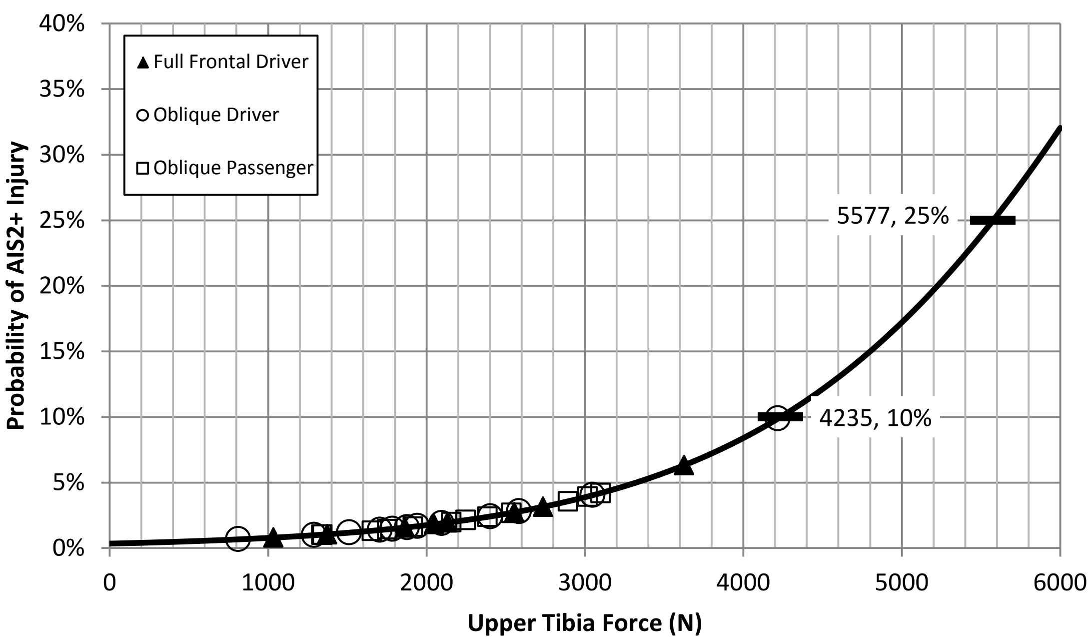


Chart T8. THOR-50M Upper Tibia Force - Test Data and p(AIS2+) Injury



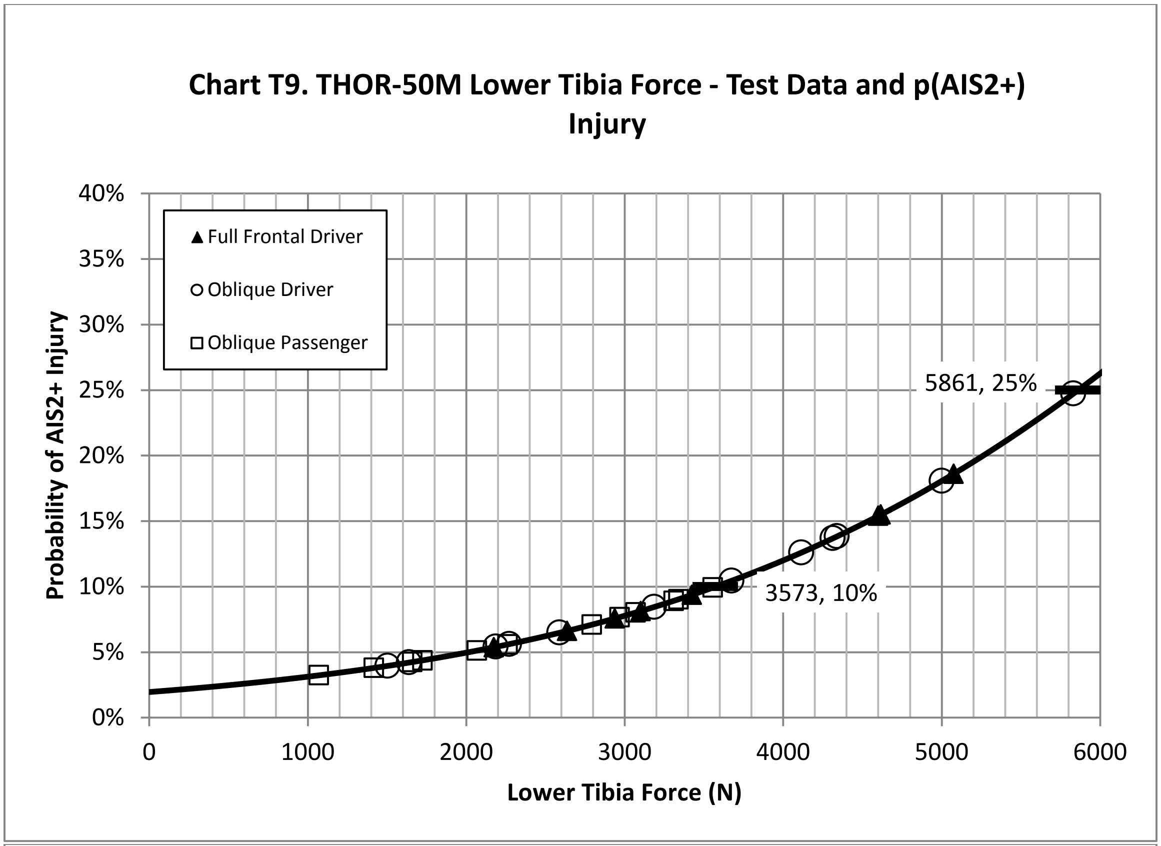


Chart T9. THOR-50M Lower Tibia Force - Test Data and p(AIS2+) Injury
Full Frontal Driver
Oblique Driver
Oblique Passenger
5861, 25%
3573, 10%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Probability of AIS2+ Injury
0
1000
2000
3000
4000
5000
6000
Lower Tibia Force (N)

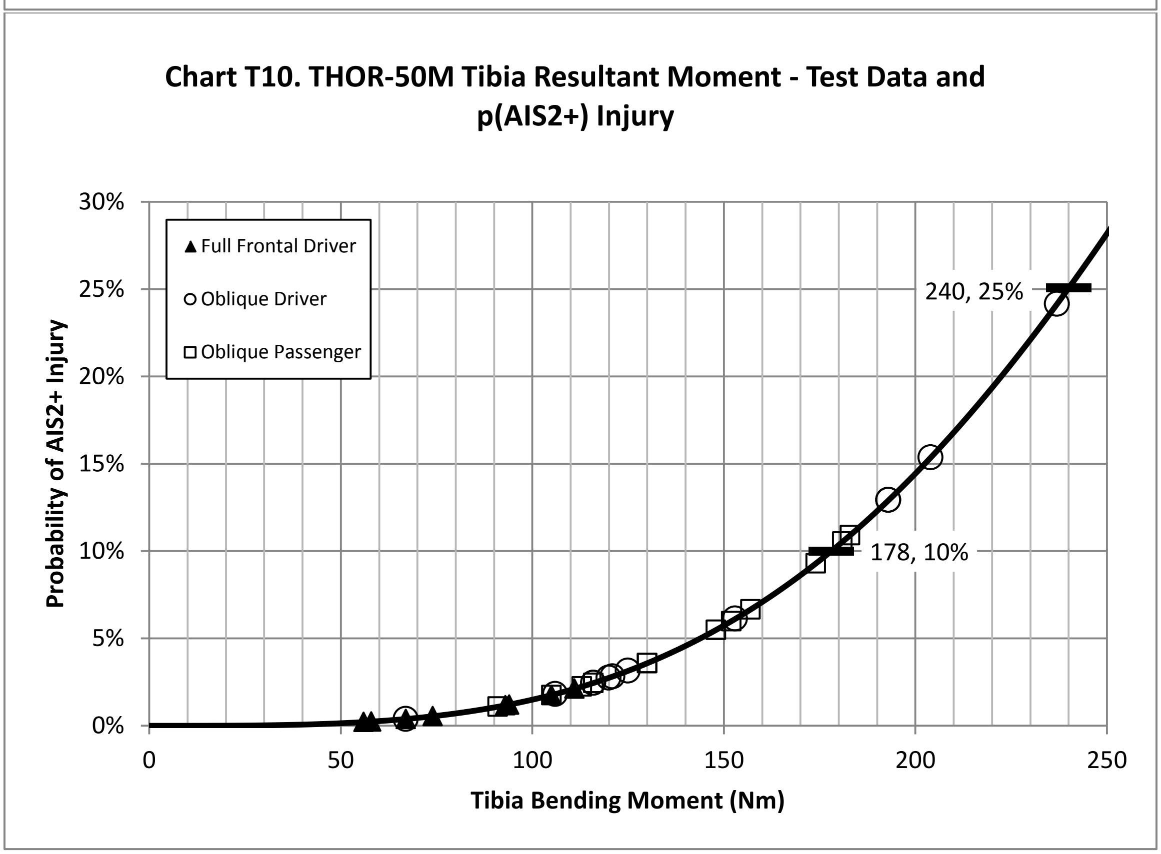


Chart T10. THOR-50M Tibia Resultant Moment - Test Data and p(AIS2+) Injury
Full Frontal Driver
Oblique Driver
Oblique Passenger
240, 25%
178, 10%
30%
25%
20%
15%
10%
5%
0%
Probability of AIS2+ Injury
0
50
100
150
200
250
Tibia Bending Moment (Nm)

Chart H1. HIII-5F HIC_{15} - Test Data and p(AIS3+) Injury

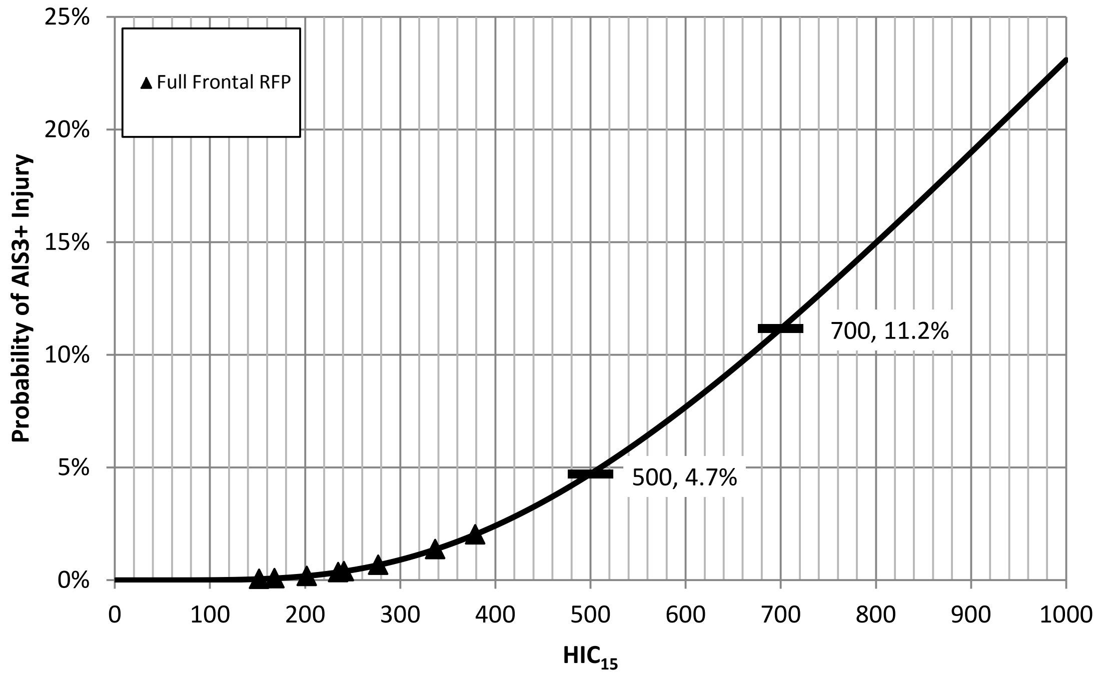
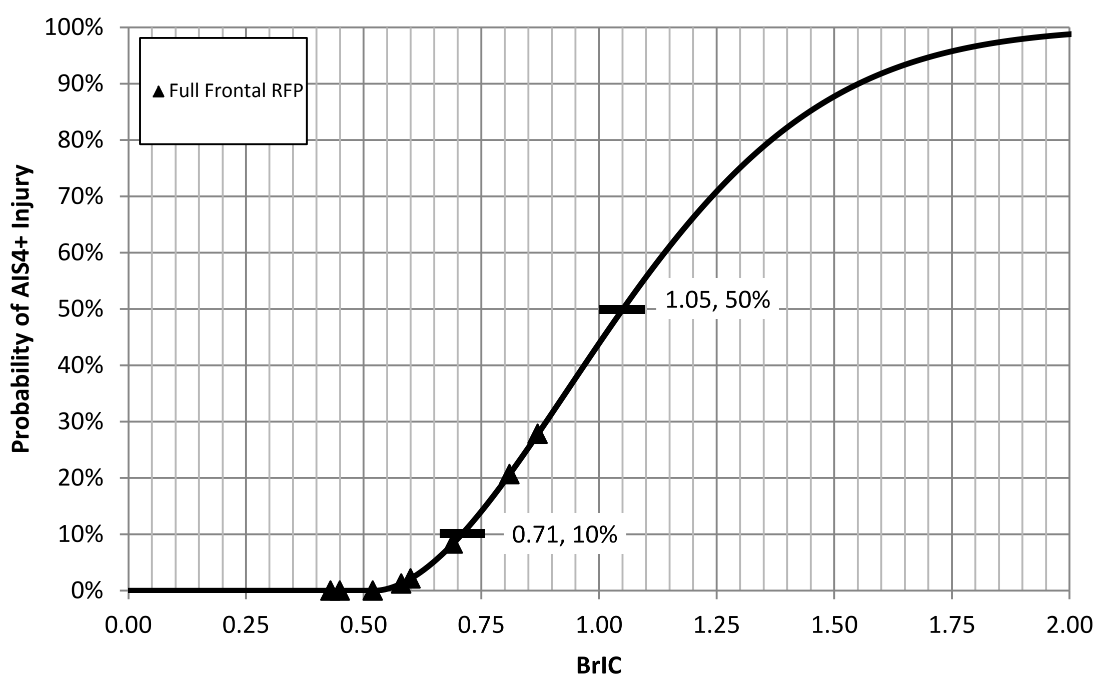


Chart H2. HIII-5F BrIC - Test Data and p(AIS4+) Injury



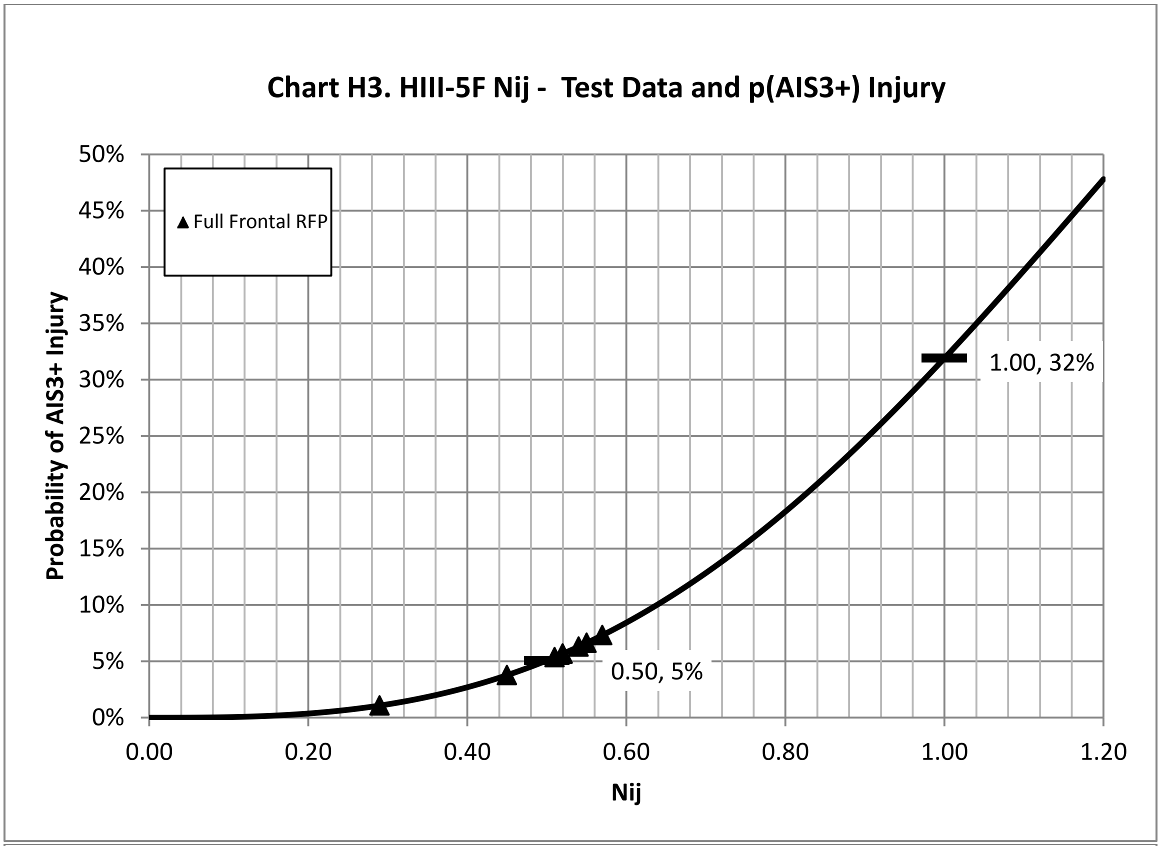


Chart H3. HIII-5F Nij - Test Data and p(AIS3+) Injury
Full Frontal RFP
1.00, 32%
0.50, 5%
Probability of AIS3+ Injury
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Nij

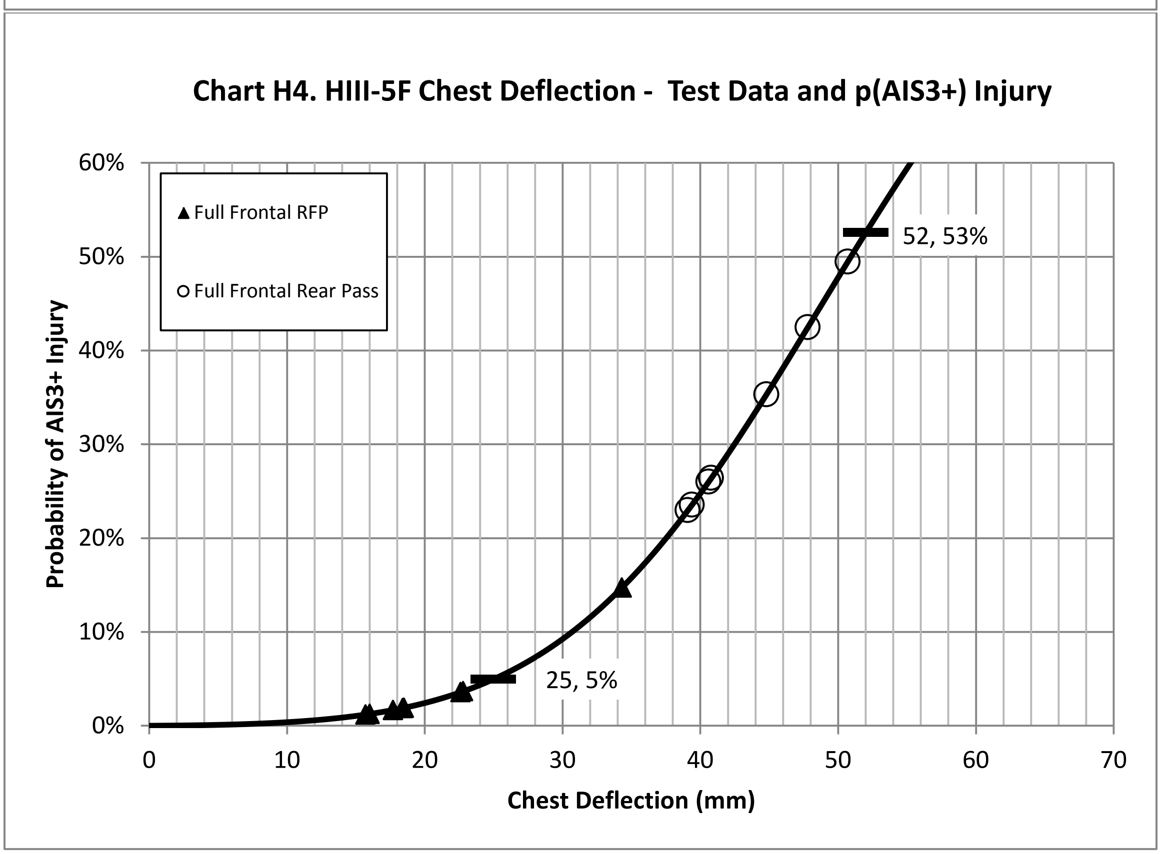


Chart H4. HIII-5F Chest Deflection - Test Data and p(AIS3+) Injury
Full Frontal RFP
Full Frontal Rear Pass
52, 53%
25, 5%
Probability of AIS3+ Injury
60%
50%
40%
30%
20%
10%
0%
0
10
20
30
40
50
60
70
Chest Deflection (mm)

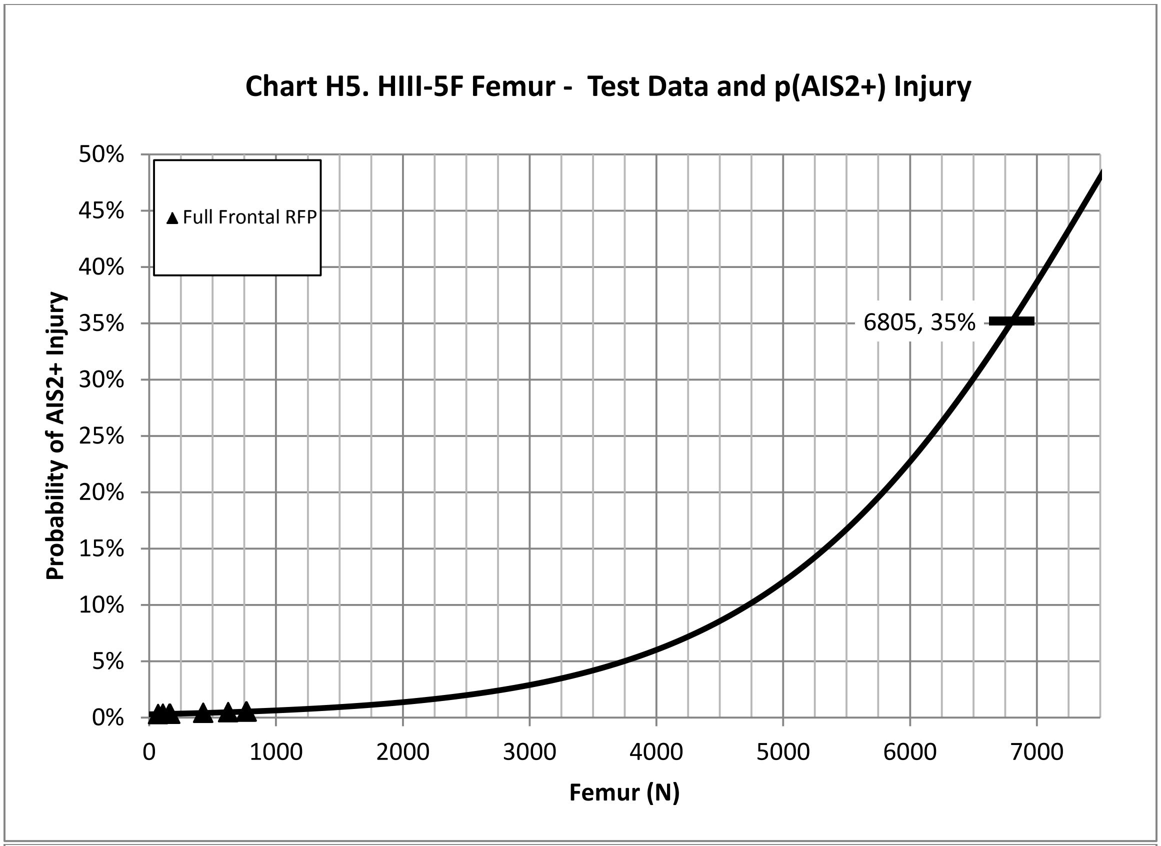


Chart H5. HIII-5F Femur - Test Data and p(AIS2+) Injury
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Probability of AIS2+ Injury
Full Frontal RFP
6805, 35%
0
1000
2000
3000
4000
5000
6000
7000
Femur (N)

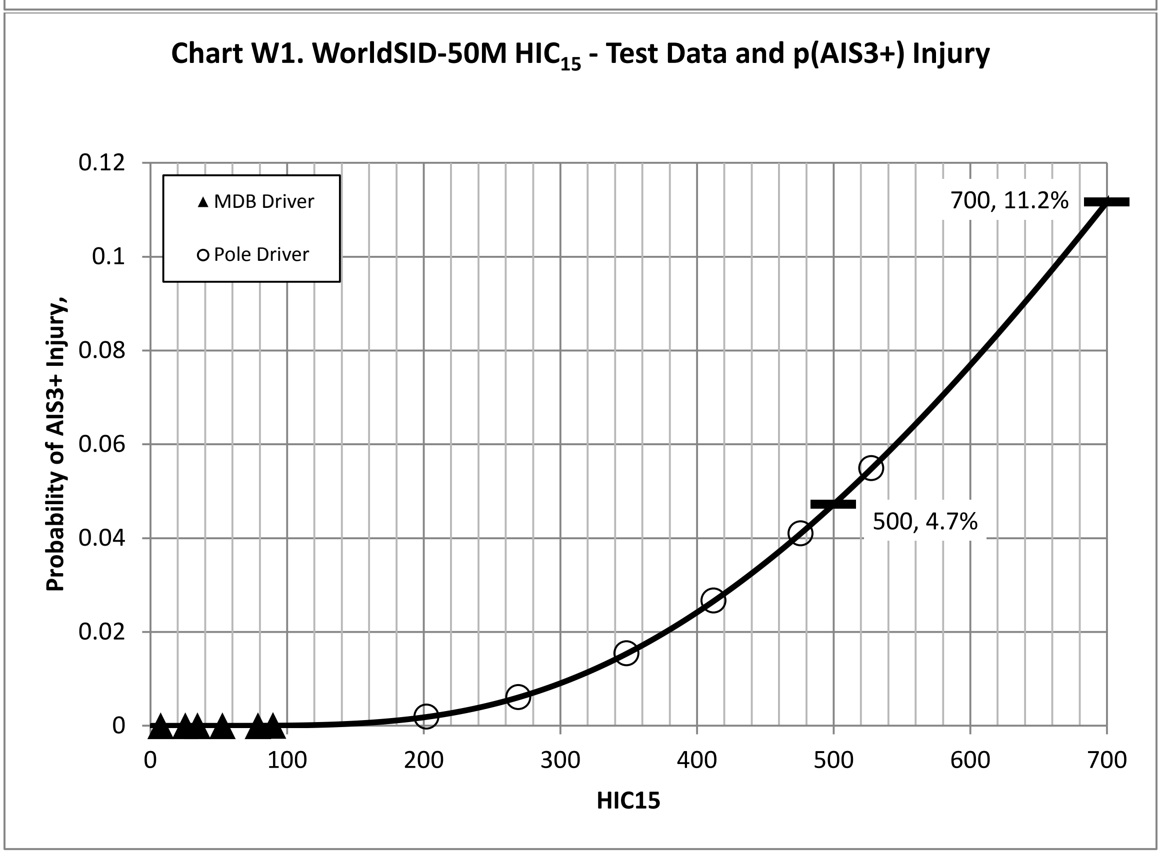


Chart W1. WorldSID-50M HIC15 - Test Data and p(AIS3+) Injury
0.12
0.1
0.08
0.06
0.04
0.02
0
Probability of AIS3+ Injury,
MDB Driver
Pole Driver
700, 11.2%
500, 4.7%
0
100
200
300
400
500
600
700
HIC15

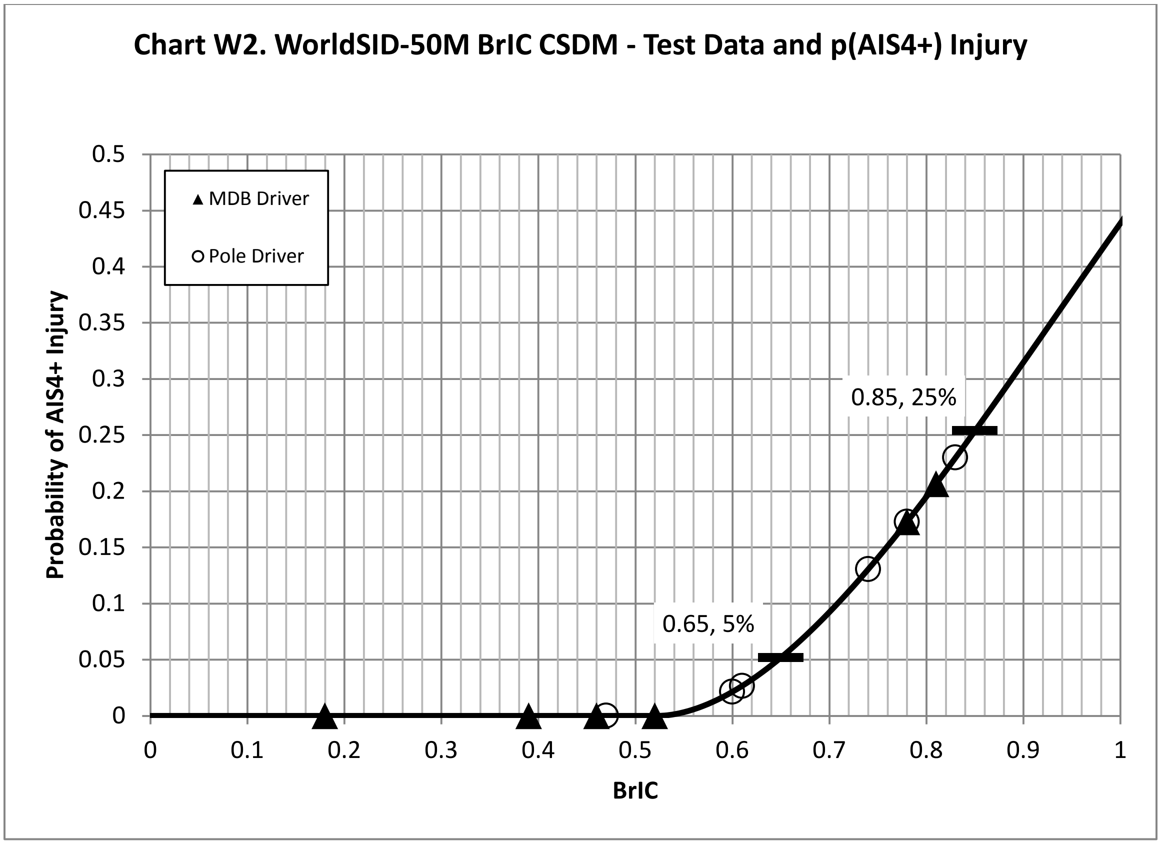


Chart W2. WorldSID-50M BrIC CSDM - Test Data and p(AIS4+) Injury
MDB Driver
Pole Driver
0.85, 25%
0.65, 5%
Probability of AIS4+ Injury
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
BrIC

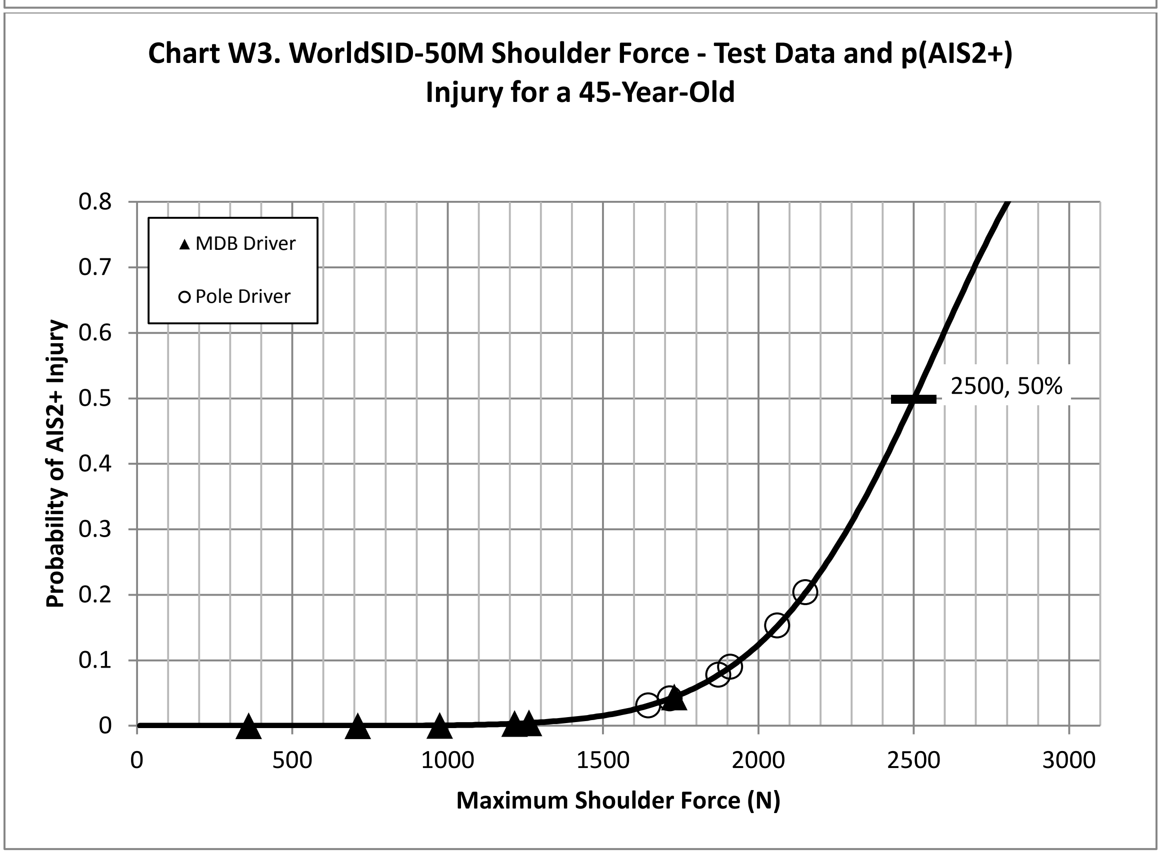


Chart W3. WorldSID-50M Shoulder Force - Test Data and p(AIS2+) Injury for a 45-Year-Old
MDB Driver
Pole Driver
2500, 50%
Probability of AIS2+ Injury
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
500
1000
1500
2000
2500
3000
Maximum Shoulder Force (N)

Chart W4. WorldSID-50M Thoracic Skeletal Injury - Test Data and p(AIS3+) Injury for a 67-Year-Old

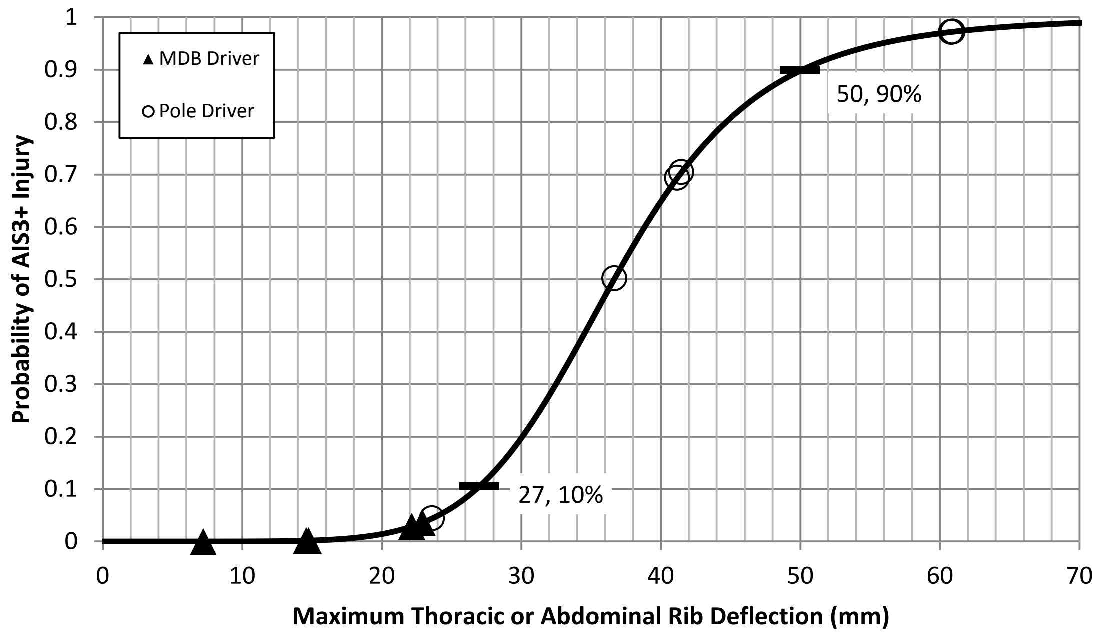


Chart W5. WorldSID-50M Thoracic Skeletal Injury - Test Data and p(AIS3+) Injury for a 45-Year-Old

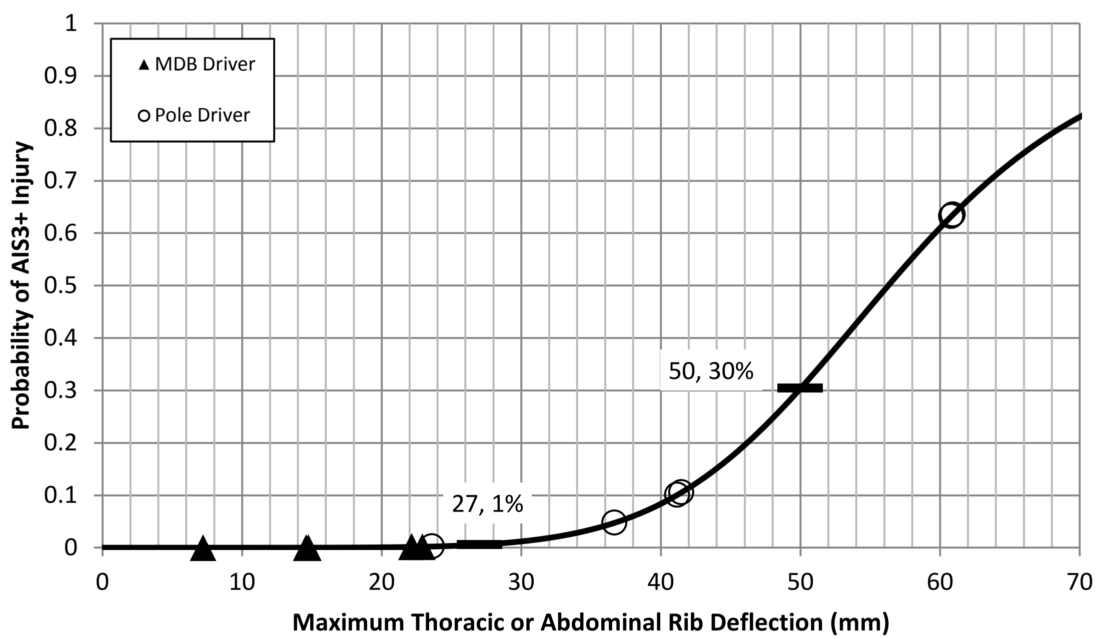


Chart W6. WorldSID-50M Abdominal Soft Tissue Injury - Test Data and p(AIS2+) Injury for a 67-Year-Old

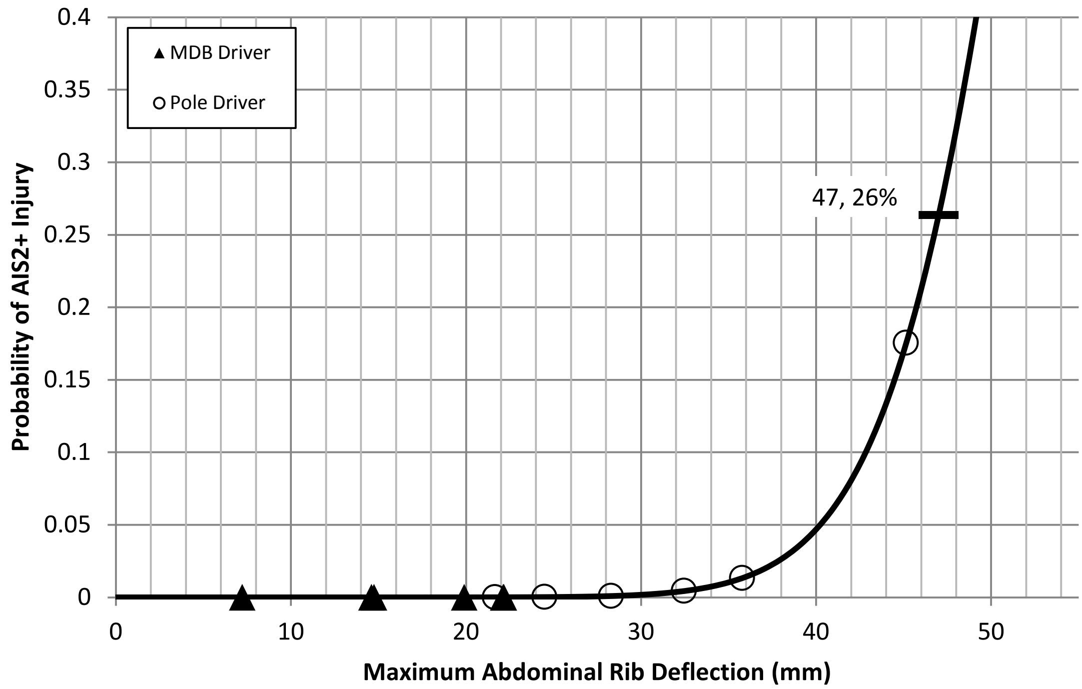


Chart W7. WorldSID-50M Pubic Force - Test Data and p(AIS2+) Injury for a 67-Year-Old

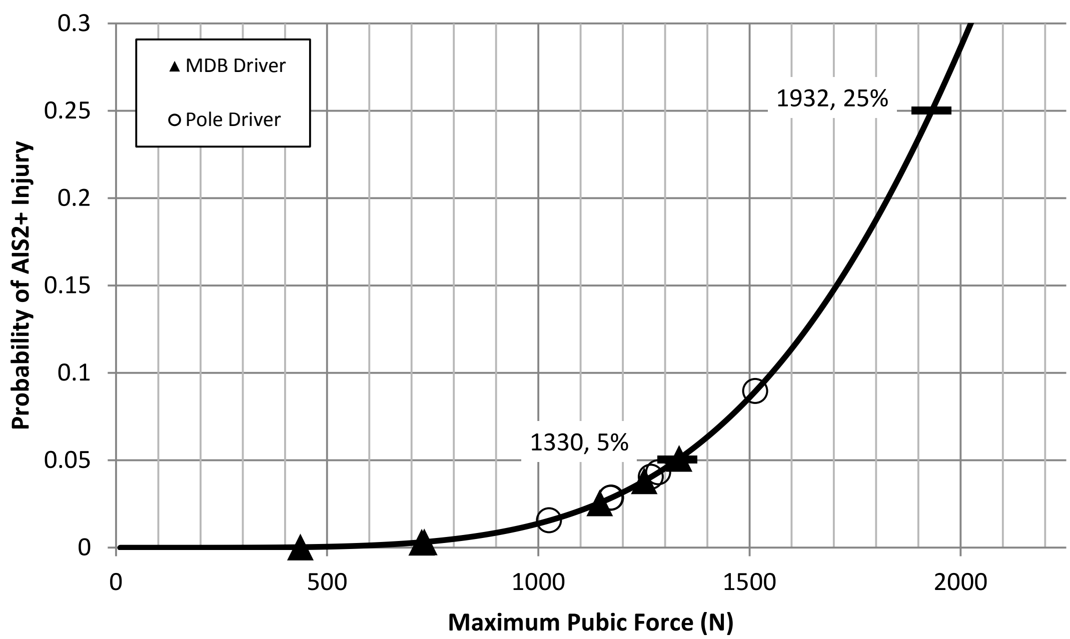


Chart W8. WorldSID-50M Sacroiliac Resultant Force - Test Data and p(AIS2+) Injury for a 67-Year-Old

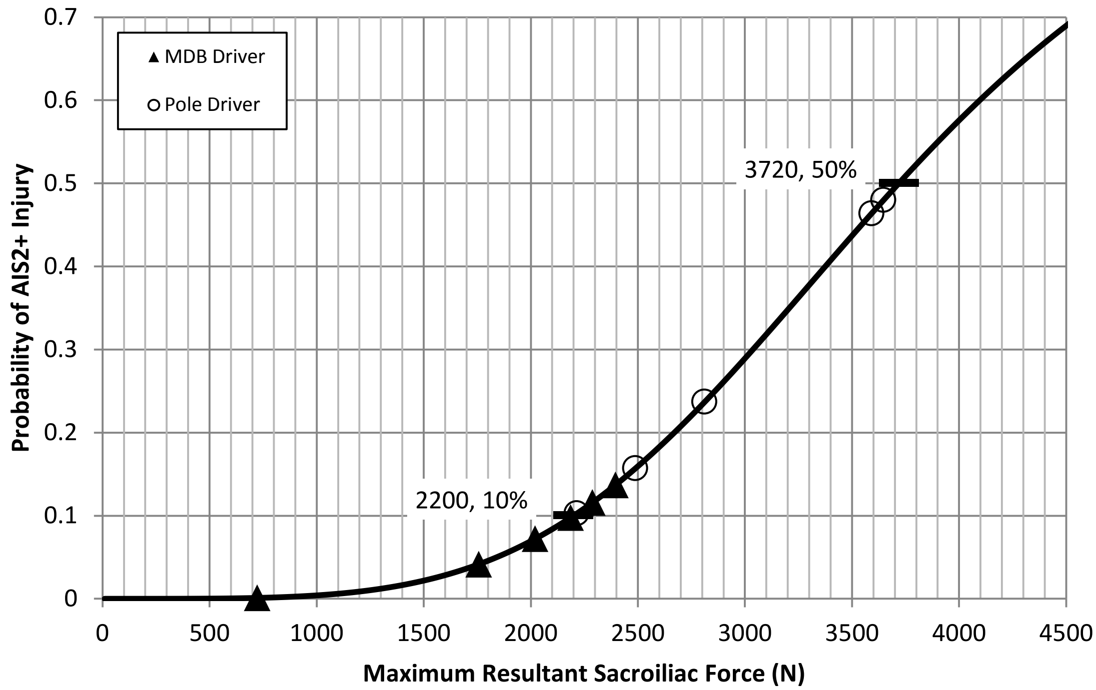
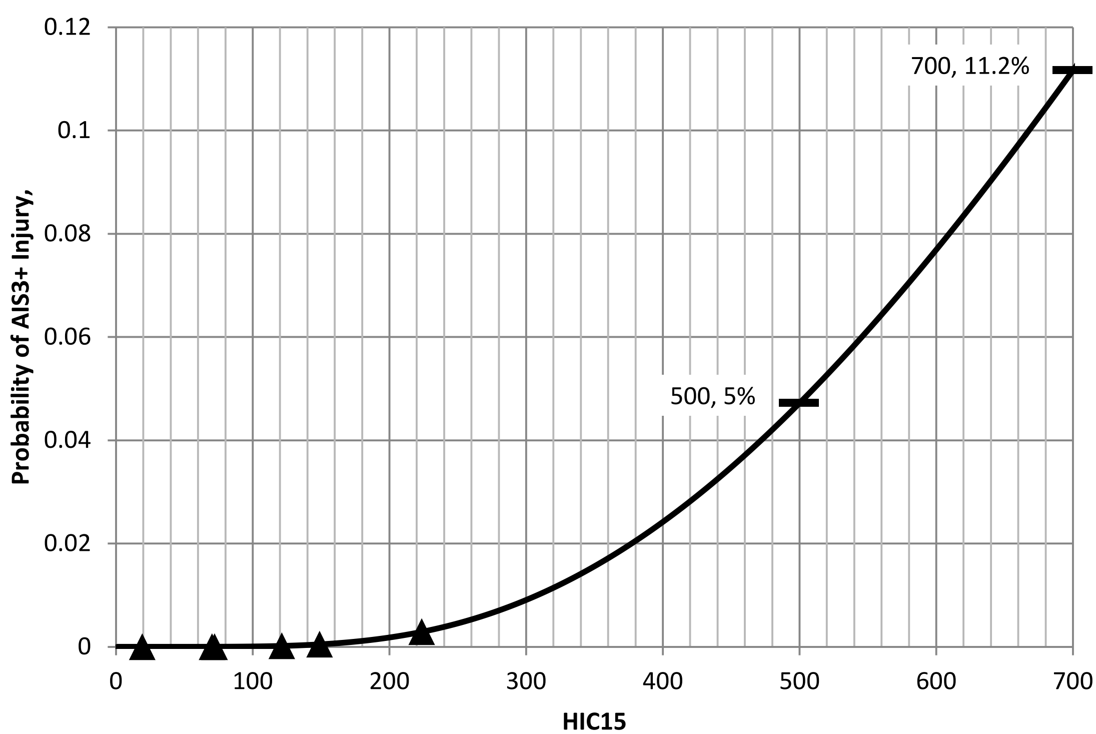


Chart S1. SID-IIs HIC_{15} - Test Data and p(AIS3+) Injury



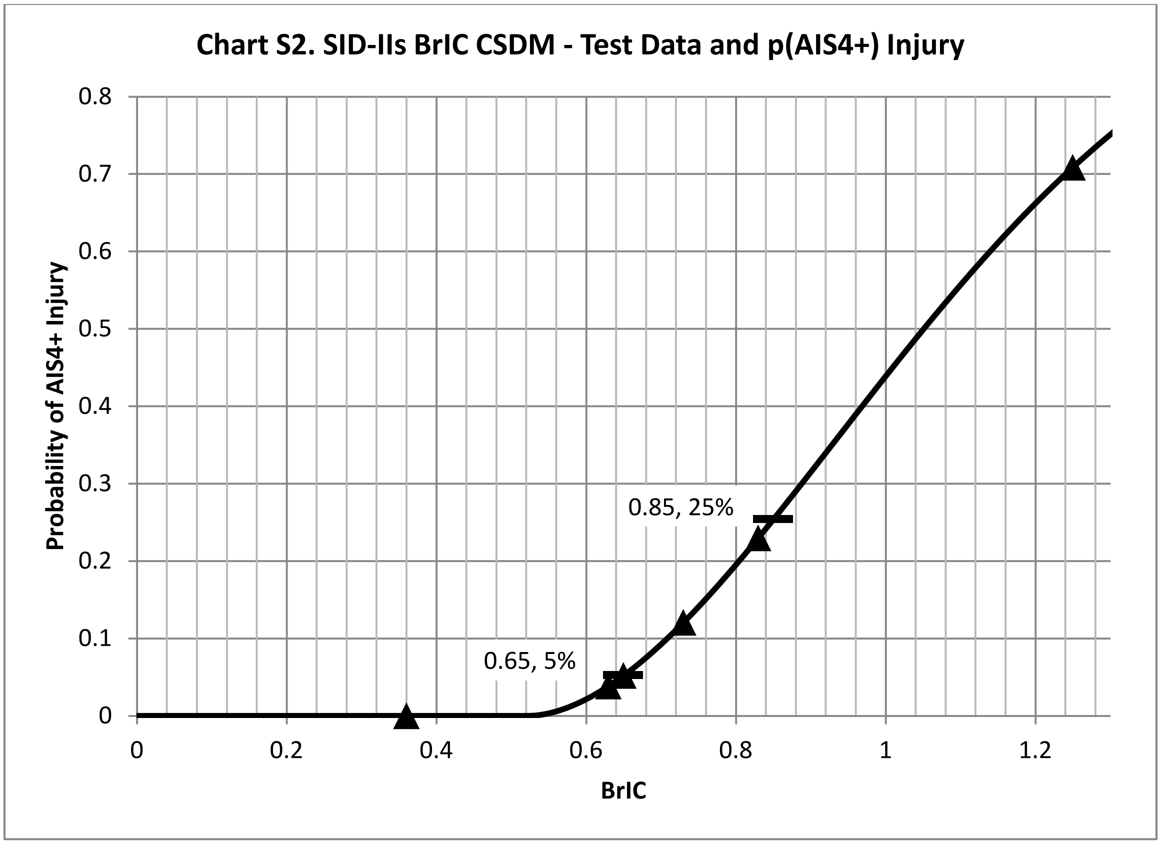


Chart S2. SID-IIs BrIC CSDM - Test Data and p(AIS4+) Injury
Probability of AIS4+ Injury
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.85, 25%
0.65, 5%
0
0.2
0.4
0.6
0.8
1
1.2
BrIC

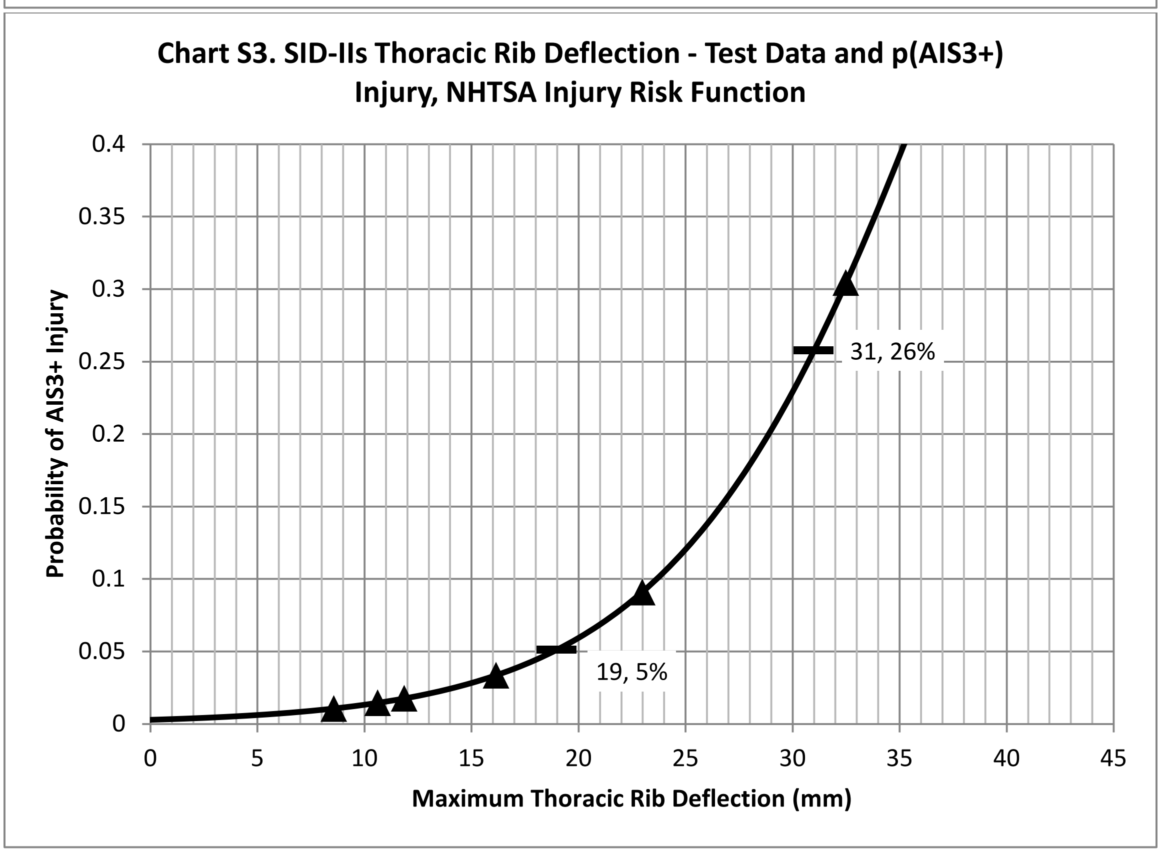


Chart S3. SID-IIs Thoracic Rib Deflection - Test Data and p(AIS3+) Injury, NHTSA Injury Risk Function
Probability of AIS3+ Injury
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
31, 26%
19, 5%
0
5
10
15
20
25
30
35
40
45
Maximum Thoracic Rib Deflection (mm)

Chart S4. SID-IIs Thoracic Rib Deflection - Test Data and p(AIS3+) Injury, Alternate Injury Risk Function

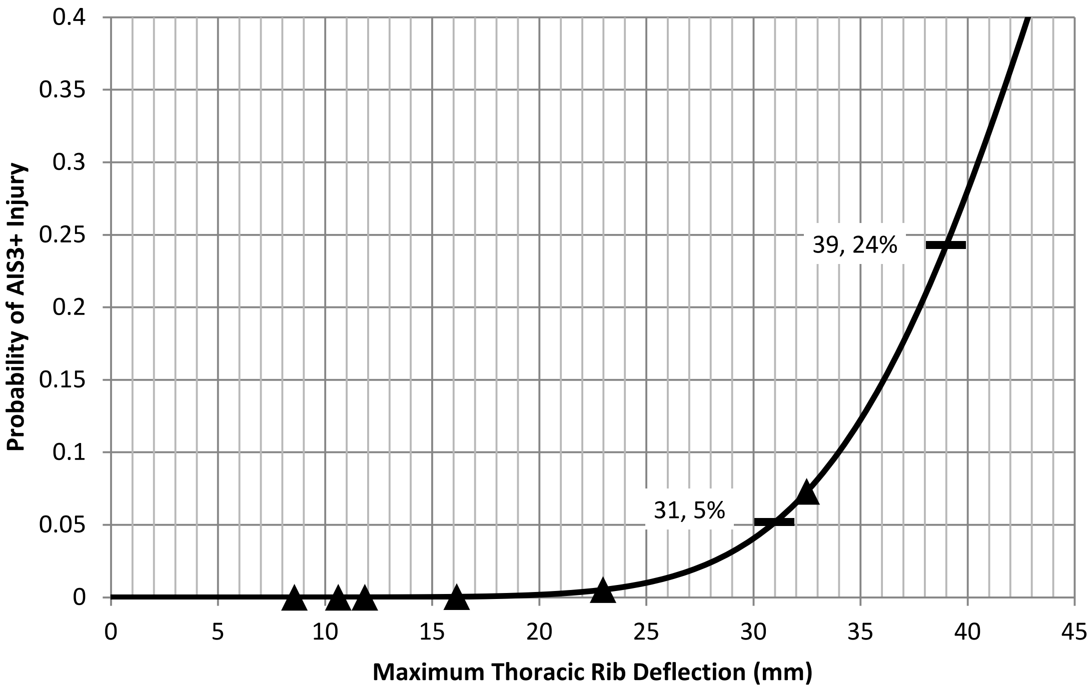


Chart S5. SID-IIs Abdominal Rib Deflection - Test Data and p(AIS4+) Injury

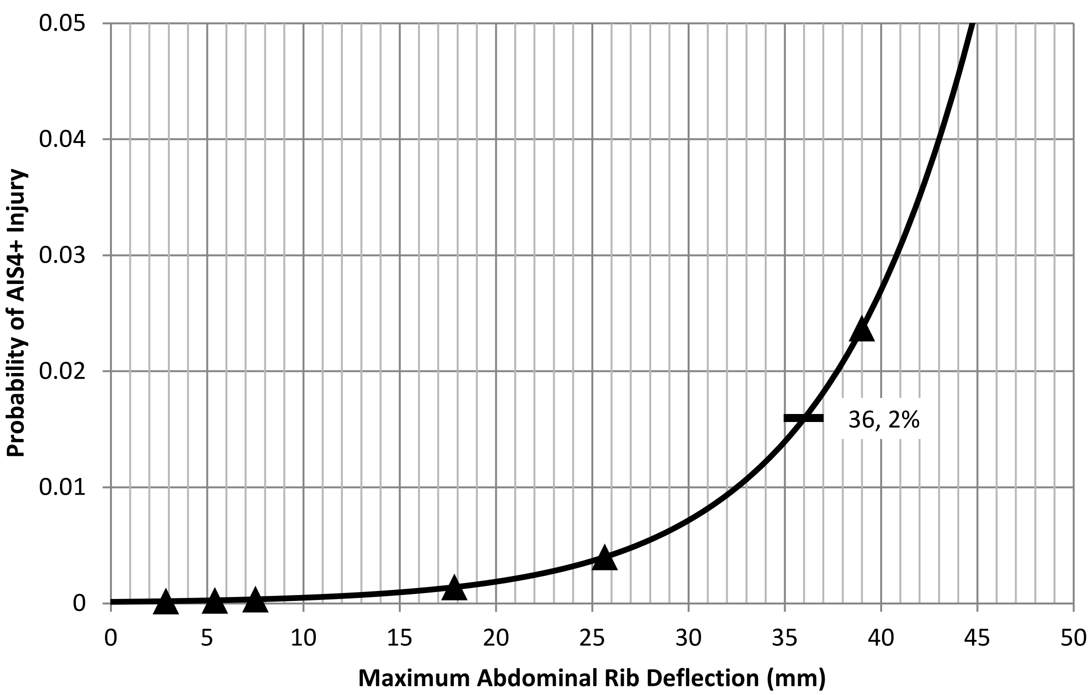
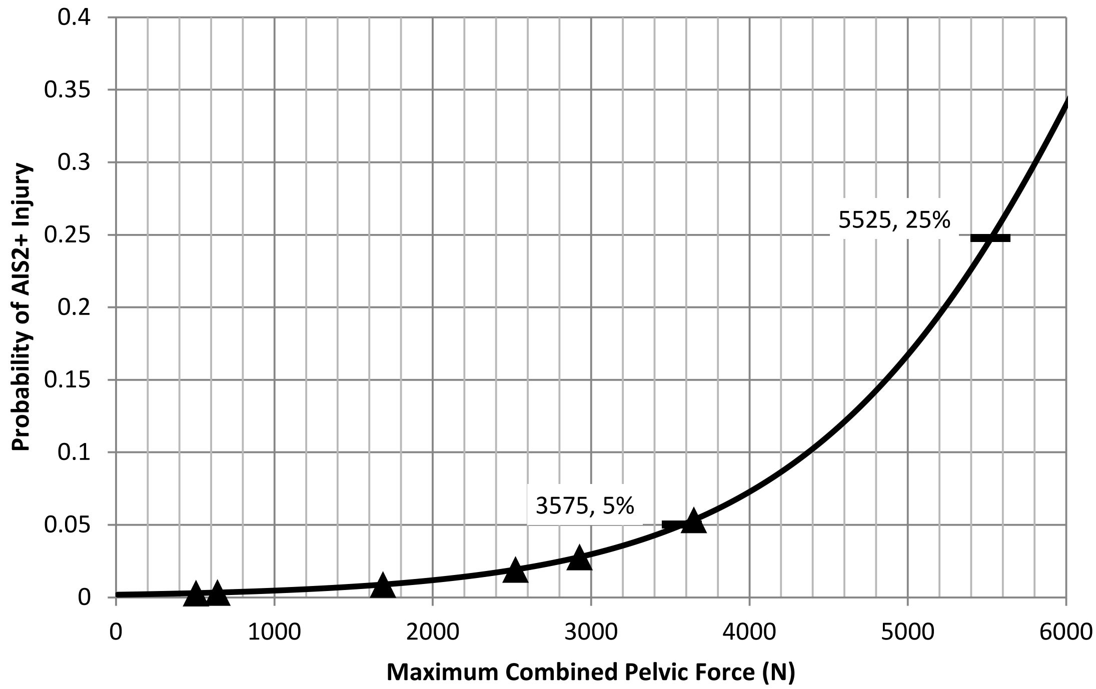


Chart S6. SID-IIs Combined Pelvic Force - Test Data and p(AIS2+) Injury



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Mark R. Rosekind, Ph.D.
Administrator

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