

DEPARTMENT OF TRANSPORTATION**National Highway Traffic Safety Administration****49 CFR Part 572**

[Docket No. NHTSA–2023–0031]

RIN 2127–AM20

Anthropomorphic Test Devices; THOR 50th Percentile Adult Male Test Dummy; Incorporation by Reference

AGENCY: National Highway Traffic Safety Administration (NHTSA), Department of Transportation (DOT).

ACTION: Notice of proposed rulemaking (NPRM).

SUMMARY: This document proposes to amend NHTSA’s regulations to include an advanced crash test dummy, the Test Device for Human Occupant Restraint (THOR) 50th percentile adult male (THOR–50M). The dummy represents an adult male of roughly average height and weight and is designed for use in frontal crash tests. NHTSA plans to issue a separate NPRM to amend Federal Motor Vehicle Safety Standard (FMVSS) No. 208, “Occupant crash protection,” to specify the THOR–50M as an alternative (at the vehicle manufacturer’s option) to the 50th percentile adult male dummy currently specified in FMVSS No. 208 for use in frontal crash compliance tests.

DATES: You should submit your comments early enough to be received not later than November 6, 2023.

Proposed Effective Date: Since this rulemaking action would not impose requirements on anyone, we are proposing that the final rule would be effective on publication in the **Federal Register**.

ADDRESSES: You may submit comments electronically to the docket identified in the heading of this document by visiting the Federal eRulemaking Portal at <http://www.regulations.gov>. Follow the online instructions for submitting comments.

Alternatively, you can file comments using the following methods:

- *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 or Courier:* West Building Ground Floor, Room W12–140, 1200 New Jersey Avenue SE, between 9 a.m. and 5 p.m. ET, Monday through Friday, except Federal holidays. To be sure someone is there to help you, please call (202) 366–9826 before coming.

- *Fax:* (202) 493–2251.

Instructions: All submissions must include the agency name and docket number or Regulatory Information Number (RIN) for this rulemaking. For detailed instructions on submitting comments and additional information on the rulemaking process, 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. Please see the Privacy Act heading below.

Docket: For access to the docket to read background documents or comments received, go to <http://www.regulations.gov>. You may also access the docket at 1200 New Jersey Avenue SE, West Building, Room W12–140, Washington, DC 20590, between 9 a.m. and 5 p.m., Monday through Friday, except Federal Holidays. Telephone: 202–366–9826.

Confidential Business Information: If you claim that any of the information in your comment (including any additional documents or attachments) constitutes confidential business information within the meaning of 5 U.S.C. 552(b)(4) or is protected from disclosure pursuant to 18 U.S.C. 1905, please see the detailed instructions given under the Public Participation heading of the Supplementary Information section of this document.

Privacy Act: Please see the Privacy Act heading under the Regulatory Analyses section of this document.

FOR FURTHER INFORMATION CONTACT: For non-legal issues, you may contact Mr. Garry Brock, Office of Crashworthiness Standards, Telephone: (202) 366–1740; Email: Garry.Brock@dot.gov; Facsimile: (202) 493–2739. For legal issues, you may contact Mr. John Piazza, Office of Chief Counsel, Telephone: (202) 366–2992; Email: John.Piazza@dot.gov; Facsimile: (202) 366–3820. The address of these officials is: the National Highway Traffic Safety Administration, 1200 New Jersey Avenue SE, Washington, DC 20590.

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I. Executive Summary

This document proposes to amend NHTSA’s regulation on anthropomorphic test devices—or, more colloquially, crash test dummies—to include an advanced crash test dummy, the Test Device for Human Occupant Restraint (THOR) 50th percentile adult male (THOR–50M). The dummy represents an adult male of roughly average height and weight and is designed for use in frontal crash tests.

Crash test dummies are complex instruments that simulate the response of a human occupant in a crash. Each type of test dummy is designed for use in specific types of crashes (for instance, frontal or side) and is instrumented with sensors to measure the forces that would have been experienced by a human occupant in a similar crash in the real world. These measurements are then used to assess the potential for injury.

Crash test dummies are used by NHTSA and by the broader vehicle safety community in a variety of ways.

NHTSA uses crash test dummies to test vehicles for compliance with Federal Motor Vehicle Safety Standards (FMVSSs) and to determine vehicle crashworthiness ratings for the New Car Assessment Program's (NCAP) 5-Star Safety Ratings, as well as to conduct vehicle safety research. Crash test dummies are also used by regulatory authorities in other countries and regions, third-party vehicle rating programs, motor vehicle and equipment manufacturers, and others to evaluate vehicle safety and design safer vehicles and equipment.

The dummies NHTSA currently uses in FMVSS compliance testing and NCAP are documented in 49 CFR part 572, Anthropomorphic Test Devices. Part 572 sets out detailed design information, including engineering drawings and procedures for assembly and inspection. These are intended to describe the dummy with sufficient detail so that it is an objective measuring tool that produces consistent responses. NHTSA has codified numerous dummies that range in sex, size, age, and measurement capability. This includes dummies representing midsize adult males, small-stature adult females, infants, toddlers, and older children.¹ These dummies are meant to provide a range of body types in order to maximize data and test results that can assess injury and fatality risks in a range of crash outcomes. The 50th percentile male dummy currently defined in Part 572 for frontal impacts is the Hybrid III-50M, which NHTSA uses to test for compliance with the frontal crash test requirements in FMVSS No. 208, "Occupant crash protection" and to rate vehicles for NCAP. NHTSA added the HIII-50M to Part 572 in 1986.

NHTSA is continually researching and improving its test dummies and has been researching advanced test dummies since the implementation of the HIII-50M. An initial THOR-50M design was published in 2001. There are currently two different THOR dummies, the THOR-50M, and one under development that represents a small-statured adult female, the THOR 5th percentile adult female (THOR-05F). Although this proposal is limited to the THOR-50M, we anticipate publishing a rulemaking proposal in the near future to add the THOR-05F to Part 572.

¹ This reflects a "bookend" approach to testing vehicles for crashworthiness, in which a range of occupant types, bookended by an average male and a small-stature female, is tested. NHTSA is currently supporting research to assess the possible benefits of developing new crash test dummies, such as a 50th percentile female crash test dummy.

The THOR-50M improves on the HIII-50M in a number of ways. It responds more like a human occupant in a crash and its advanced instrumentation enables it to more accurately measure the forces acting on the dummy. As a result, it is better able to predict the risk of injury to a human occupant. This should help vehicle designers develop and test improved occupant restraint systems (e.g., advanced seat belts and air bags) as well as the types of novel vehicle seating configurations likely to be used in highly automated vehicles.

NHTSA has tentatively concluded that the THOR-50M is sufficiently biofidelic, exhibits repeatable and reproducible performance, and is sufficiently durable. As such, we believe that it would be suitable for use in regulatory compliance testing and is therefore suitable for incorporation into Part 572. NHTSA and others have already taken advantage of the THOR-50M's advanced capabilities. NHTSA, vehicle and restraint manufacturers, and vehicle safety researchers have used the THOR-50M to evaluate vehicle crashworthiness and develop occupant protection countermeasures for frontal and oblique crashes. The European New Car Assessment Programme (Euro NCAP) has officially adopted the THOR-50M and is currently rating vehicles using the dummy. Moreover, the Economic Commission for Europe is considering adopting the THOR-50M for use in frontal crash testing under its vehicle safety regulations.

NHTSA expects a variety of benefits from incorporating the THOR-50M into Part 572. The definition of the THOR-50M in Part 572 will enable its use in regulatory and consumer information programs, both within NHTSA and externally. NHTSA believes that the THOR-50M's enhancements will lead to more effective restraint system designs and more informative comparisons of the safety of different vehicles. Because of this—as well as the fact that manufacturers are already using the dummy—we believe vehicle manufacturers would choose to certify vehicles to FMVSS No. 208 using the THOR-50M if given the option. This would enable manufacturers to streamline testing by using the same dummy for research and development and to verify compliance. NHTSA anticipates issuing a proposal in the near future to amend FMVSS No. 208 to specify the THOR-50M as an alternative (at the vehicle manufacturer's option) to the HIII-50M test dummy for use in frontal crash compliance tests. There would be other benefits as well. For instance, NHTSA's test dummies are

used in a range of applications beyond FMVSS compliance testing—such as NCAP testing, standards and regulations in other transportation modes, and research. Including the dummy design in Part 572 will help provide a suitable, standardized, and objective test tool for the safety community.

II. Background

This document proposes to amend 49 CFR part 572, Anthropomorphic Test Devices, to include an advanced test dummy representing a 50th percentile adult male, the Test Device for Human Occupant Restraint (THOR-50M).² The THOR-50M is a test dummy designed for use in frontal crash tests. It has several advanced capabilities and advantages over the Hybrid III 50th percentile male test dummy (HIII-50M) that is currently specified in Part 572 and used in frontal crash testing under FMVSS No. 208, "Occupant crash protection," and the U.S. New Car Assessment Program (NCAP).³ NHTSA plans to issue a proposal in the near future to amend FMVSS No. 208 to specify the THOR-50M as an alternative to the HIII-50M for use in frontal crash tests.⁴

This document proposes incorporating by reference in Part 572 a parts list, design drawings, qualification procedures, and procedures for assembly, disassembly, and inspection, to ensure that THOR-50M dummies are uniform in design, construction, and response. This section provides background on NHTSA's crash test dummies, the development of the THOR-50M, and its use in other jurisdictions, among other topics.

Overview of Use of Vehicle Crash Test Dummies

Anthropomorphic Test Devices (ATDs)—or crash test dummies—are complex instruments that serve as human surrogates in vehicle crash tests (among other types of tests⁵). Test dummies simulate the response of a human occupant in a crash and measure

² NHTSA has registered the term "THOR" as a trademark (U.S. Registration No. 5,104,395).

³ The HIII-50M is also specified for use in FMVSS No. 202a, Head Restraints, in an optional rear impact dynamic test.

⁴ FMVSS No. 208 THOR-50M Compliance Option (RIN 2127-AM21), Spring 2023 Unified Agenda of Regulatory and Deregulatory Actions; Department of Transportation, available at <https://www.reginfo.gov/public/do/eAgendaViewRule?pubId=2023048&RIN=2127-AM21>.

⁵ NHTSA also uses ATDs in sled tests (which simulate a vehicle crash by using a simplified test buck to represent a vehicle), and out-of-position air bag tests. ATDs are also used outside the vehicle safety context to measure human responses in a variety of other areas, such as aviation and aeronautics.

the effects of the crash forces on the occupant. They are used to estimate the severity of the injuries that would have been experienced by a human occupant in a similar crash in the real world. Each type of test dummy is designed for use in specific types of crashes (frontal, side, etc.), and is instrumented with a wide array of sensors to measure the forces that would be relevant in the type of crash for which it is designed and to assess the potential for injury. The more closely a dummy represents how an actual human would respond, the more biofidelic the dummy is considered to be.

NHTSA and the vehicle safety community use crash test dummies in a variety of ways. NHTSA uses crash test dummies for vehicle compliance testing, safety ratings, and safety research. NHTSA's Federal Motor Vehicle Safety Standards establish mandatory minimum safety performance requirements for motor vehicles and motor vehicle equipment. Vehicles and equipment manufactured for sale in the United States must be certified to comply with all applicable FMVSSs. A number of the FMVSSs specify crash tests, using specified dummies, that the vehicle must be certified as passing.⁶ NHTSA's vehicle safety compliance program selects vehicles (and equipment) for compliance testing every year; this includes crash testing vehicles to ensure that they comply with the performance requirements that are evaluated by means of crash tests. NHTSA's NCAP also evaluates vehicle performance in crash tests using dummies as part of its 5-Star Safety Ratings. Finally, NHTSA's vehicle safety research program uses crash test dummies to evaluate new vehicle safety countermeasures and develop new vehicle crash testing protocols. Dummies are also used outside of NHTSA by regulatory authorities in other countries and regions, for third-party ratings (such as Insurance Institute for Highway Safety ratings), and by industry and the vehicle safety community to measure performance and design safer vehicles.

⁶ The FMVSS specify the procedures NHTSA will use in compliance testing, including what dummies it will use for testing. Part 572 specifies the dummies. While manufacturers must exercise reasonable care in certifying that their products meet applicable standards, they are not required to follow the compliance test procedures set forth in a standard or use the dummy specified in Part 572. See, e.g., 38 FR 12934, 12935 (May 17, 1973) ("Manufacturers should understand that they are not required to test their products in any particular manner, as long as they exercise due care that their products will meet the requirements when tested by the NHTSA under the procedures specified in the standard.").

The dummies NHTSA currently uses in FMVSS compliance testing and in NCAP are documented in 49 CFR part 572, Anthropomorphic Test Devices. Part 572 sets out detailed design information, including engineering drawings and procedures for assembly and inspection. These are all intended to describe the dummy with sufficient detail so that it produces consistent responses when it is tested under similar conditions in repeated tests at the same laboratory (repeatability) or between multiple dummies manufactured to the same specification used at different test laboratories (reproducibility).

FMVSS No. 208 Frontal Crash Tests Using a 50th Percentile Male Dummy

FMVSS No. 208, "Occupant crash protection," specifies a variety of different requirements using crash test dummies. This includes frontal crash tests in which the vehicle is moving and tests that are performed with a stationary vehicle and are intended to help ensure that air bags do not harm small-stature occupants and children. The test dummies used in FMVSS No. 208 were designed to evaluate vehicle performance in frontal crashes and are fitted with a variety of instruments to measure the forces typically experienced by an occupant in a frontal crash.⁷ The 50th percentile male dummy that is currently specified for use in FMVSS No. 208 is the Hybrid III-50M.⁸ The HIII-50M has been specified in FMVSS No. 208 since 1986,⁹ and replaced an even earlier dummy, the Hybrid II. FMVSS No. 208 also specifies tests using dummies representing a 5th percentile female, a 6-year-old, a 3-year-old, and an infant.¹⁰

FMVSS No. 208 specifies two tests (both of which are crash tests) using the HIII-50M: a crash test in which the dummy is belted and the test vehicle, traveling up to 35 mph, impacts a rigid barrier at a ninety-degree angle or

⁷ Other FMVSS specify different types of crash or sled tests that use different dummies. For example, FMVSS No. 214, Side Impact Protection, specifies two crash tests (simulating a side impact with a vehicle and a pole impact). This test uses two different side impact dummies.

⁸ Part 572, Subpart E.

⁹ 51 FR 26688 (July 25, 1986) (final rule adding HIII-50M). The Hybrid III-50M was developed by General Motors and added to Part 572 and for use in FMVSS No. 208 in response to a petition for rulemaking from GM.

¹⁰ This reflects a "bookend" approach to testing vehicles for crashworthiness, in which a range of occupant types, bookended by an average male and a small-stature female, is tested. NHTSA is currently supporting research to assess the possible benefits of developing new crash test dummies, such as a 50th percentile female crash test dummy.

perpendicular;¹¹ and a crash test in which the dummy is unbelted and the test vehicle, traveling 20–25 mph, impacts a rigid barrier at an angle ranging from ± 30 degrees oblique from perpendicular.¹² NCAP also evaluates vehicle performance in a frontal crash test at 35 mph using a belted HIII-50M dummy.

FMVSS No. 208 regulates vehicle performance in these crash tests by specifying injury criteria and associated injury assessment reference values (IARVs). Injury criteria and their respective risk functions relate instrumentation measurements to a predicted risk of human injury. Each IARV is a maximum value or threshold for a specific injury criterion that may not be exceeded when the vehicle is tested with the specified dummy under the specified test conditions and procedures. For example, FMVSS No. 208 specifies a head injury criterion, HIC₁₅, with an IARV of 700. Thus, if NHTSA runs a compliance frontal crash test and the calculated HIC₁₅ value exceeds 700, this would be considered an apparent noncompliance. FMVSS No. 208 specifies the following injury criteria for the HIII-50M: a head injury criterion (HIC₁₅);¹³ a thoracic acceleration criterion;¹⁴ a chest deflection criterion;¹⁵ a criterion based on the maximum force transmitted axially through the upper leg (femur);¹⁶ and three neck injury criteria.¹⁷

Development of the THOR ATDs

NHTSA has continually conducted research into advancements in crash safety, including the development of advanced dummies.¹⁸ The goal of this research has been to create ATDs that represent the responses of human occupants in modern vehicle environments with advanced restraint systems. This research has led to the development of the two Test Device for Human Occupant Restraint (THOR) ATDs, designed primarily for use in frontal and frontal oblique motor vehicle crash environments. There are currently two main implementations of the THOR design, both representing seated motor vehicle occupants: one representing a 50th percentile male and

¹¹ S5.1.1(b)(2), S14.5.1(b).

¹² S5.1.2(b), S14.5.2.

¹³ S6.2(b).

¹⁴ S6.3.

¹⁵ S6.4.

¹⁶ S6.5.

¹⁷ S6.6.

¹⁸ Haffner, M., Rangarajan, N., Artis, M., Beach, D., Eppinger, R., Shams, T., "Foundations and Elements of the NHTSA THOR Alpha ATD Design," The 17th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 458, 2001.

one representing a 5th percentile female.

Development of THOR–50M

The initial design version of the THOR–50M, introduced in 2001, was the THOR Alpha.¹⁹ The THOR Alpha, which integrated some components from the earlier prototype demonstrator known as the Trauma Assessment Device, introduced some of the features that exist in the current version of THOR–50M, including the multi-direction neck, human-like ribcage geometry and impact response, multi-point thorax and abdomen deflection measurement system, and instrumented lower extremities. NHTSA refined the THOR Alpha design and reintroduced it in 2005 as the THOR–NT,²⁰ which included updates to anthropometry, durability, usability, biofidelity, and fit and finish. In 2011, NHTSA, in coordination with the SAE International (SAE) THOR Evaluation Task Group, introduced a modification package (Mod Kit) intended to enhance the biofidelity, repeatability, durability, and usability of the THOR–NT.²¹ After the introduction of the THOR Mod Kit, an upgrade to the Chalmers shoulder assembly that was developed through the European Union’s THORAX project was integrated into the THOR–50M design.²² The THOR–50M drawing package was then converted from the traditional measurement system to the metric system through soft conversion (where any non-metric measurements are mathematically converted to metric equivalents without changes to the physical dimensions). All fasteners were also replaced with the nearest metric equivalents. NHTSA made this integrated drawing package (with incremental improvements and corrections) publicly available online in

2015,²³ 2016,²⁴ 2020,²⁵ and 2023.²⁶ The version published in 2023 is referred to as the 2023 drawing package, which consists of two-dimensional drawings and a Parts list; this, together with the Procedures for Assembly, Disassembly, and Inspection (PADI), and qualification procedures, is referred to as the 2023 technical data package. (The version published in 2020 is referred to as the “2018 drawing package” or the “2018 technical data package.”) The version of THOR that is being proposed is the version defined in the 2023 technical data package. In 2019, NHTSA began publishing THOR–50M documentation in a new docket titled, “NHTSA Crashworthiness Research—THOR–50M Documentation.”²⁷ In addition to the documents that make up the 2018 and 2023 technical data packages, the docket folder includes the following: durability report; seating procedure; injury criteria; biofidelity report; Oblique Moving Deformable Barrier (OMDB) Repeatability and Reproducibility (R&R); and Qualification test R&R. This documentation is discussed further in Section III.B and in the relevant sections of this preamble.²⁸ NHTSA has tentatively concluded that the THOR–50M is sufficiently biofidelic, exhibits repeatable and reproducible performance, and is sufficiently durable.

²³ National Highway Traffic Safety Administration (2015). Parts List and Drawings, THOR–M Advanced Frontal Crash Test Dummy, September 2015. *Regulations.gov* Docket ID NHTSA–2015–0119–0005, available at: <https://www.regulations.gov/document/NHTSA-2015-0119-0005> (NCAP docket).

²⁴ National Highway Traffic Safety Administration (2016). Parts List and Drawings, THOR–50M Advanced Frontal Crash Test Dummy, August 2016, available at: <https://www.nhtsa.gov/es/document/thor-50m-drawing-package-august-2016.pdf>.

²⁵ National Highway Traffic Safety Administration. Parts List and Drawings, THOR–50M Advanced Frontal Crash Test Dummy, August 2018. *Regulations.gov* Docket ID NHTSA–2019–0106–0002, available at: <https://www.regulations.gov/document/NHTSA-2019-0106-0002>.

²⁶ National Highway Traffic Safety Administration. THOR 50th Percentile Male with Alternate Shoulders Frontal Crash Test Dummy Drawings, External Dimensions, and Mass Properties, THOR–50M Advanced Frontal Crash Test Dummy, August 2018. *Regulations.gov* Docket ID NHTSA–2019–0106–0013, available at: <https://www.regulations.gov/document/NHTSA-2019-0106-0013>.

²⁷ Docket NHTSA–2019–0106.

²⁸ These documents are located in the research docket, Docket No. NHTSA–2019–0106. NHTSA is not placing copies of these documents in the docket for this rulemaking action in order to avoid potential confusion from having identical documents docketed at different times in different dockets. Nevertheless, NHTSA intends these to be included as part of the rulemaking record for this rulemaking action. A memorandum explaining this is also being placed in the docket for this rulemaking.

As such, we believe that it would be suitable for use in regulatory compliance testing and is therefore suitable for incorporation into Part 572. A more detailed discussion of the technical data package is provided in Section III.B.

Development of THOR–05F

NHTSA understands that the risk of injury in a crash can depend on the occupant’s physical characteristics (e.g., height, weight, bone density) and how they interact with the restraint system and vehicle environment. To that end, NHTSA has developed comprehensive research plans to address differences in crashworthiness safety testing and outcomes, including differences in injury risk. Human body modeling research efforts are underway to consider female and male occupants and vulnerable road users of various ages, shapes, and sizes. This includes continuing and accelerating research efforts to address differences in motor vehicle safety based on physical characteristics, including sex, and making data-driven decisions supported by the research outcomes. A series of efforts is specifically focused on female occupant crash safety, spanning field data analysis, tool development, demonstration, and application.²⁹

As part of these efforts, NHTSA has been developing the THOR 5th percentile adult female frontal crash test dummy (THOR–05F). The THOR–05F represents a small adult female and has a seated height of 81.3 cm (32.0 in), approximate standing height of 151 cm (59.4 in), and weight of 49 kg (108.0 lbs). The THOR–05F has improved measurement capabilities over the Hybrid III–5F, which is specified in FMVSS No. 208 and documented in Part 572. The THOR–05F’s instrumentation is similar to that of the THOR–50M. Improved designs resulting from the development of the THOR–50M related to the head, neck, thorax, and lower extremities have also been incorporated into the design of the THOR–05F. Currently, NHTSA is evaluating the THOR–05F’s biofidelity and durability, developing design updates, injury criteria, and documentation, and assessing its utility in full-scale crash testing.

NHTSA anticipates completing the research and testing necessary to support a rulemaking for the THOR–05F

²⁹ See National Highway Traffic Safety Administration (2022). NHTSA Female Crash Safety Research Plan, November 2022. *Regulations.gov* Docket ID NHTSA–2022–0091–0002, available at: <https://www.regulations.gov/document/NHTSA-2022-0091-0002>.

¹⁹ *Id.*

²⁰ Shams, T., Rangarajan, N., McDonald, J., Wang, Y., Platten, G., Spade, C., Pope, P., Haffner, M., “Development of THOR NT: Enhancement of THOR Alpha—the NHTSA Advanced Frontal Dummy,” The 19th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 05–0455, 2005.

²¹ Ridella, S., Parent, D., “Modifications to Improve the Durability, Usability, and Biofidelity of the THOR–NT Dummy,” The 22nd International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 11–0312, 2011.

²² Lemmen, P., Been, B., Carroll, J., Hynd, D., Davidsson, J., Song, E., Lecuyer, E., “Development of an advanced frontal dummy thorax demonstrator,” Proceedings of the 2012 IRCOB Conference, 2012.

in 2023.³⁰ Possible test modes in which THOR-05F may be used include FMVSS No. 208 testing and NCAP frontal crash tests. NHTSA has placed documentation and research for the THOR-05F in an online docket and will continue adding additional research and information to this docket as it becomes available.³¹

Innovative Features of the THOR-50M

Frontal crashes are the leading cause of injuries and fatalities in occupants of motor vehicle crashes on U.S. public roadways. The vehicle front is the initial point of impact in a majority of crashes in the U.S. In 2021, 15,570 occupants of passenger cars or light trucks died, and 1,144,169 were injured, in frontal crashes.³² This suggests that even though occupant protection systems have improved over the years and saved many lives,³³ improvements to occupant protection in frontal crashes still need to be made.

The THOR-50M is designed to better evaluate the effectiveness of modern vehicle restraint systems and address the types of injuries that continue to occur. These improvements include the following:

Improved biofidelity. Biofidelity is a measure of how well a dummy replicates the response of a human. The THOR-50M was designed with advanced features that enable it to have improved biofidelity compared to the HIII-50M. The dummy's head includes a deformable facial insert that emulates human response to impact. The components in the neck representing bone and ligament structure are separate from those representing muscular structure, improving both kinematic response and injury prediction. The thorax simulates the shape and impact response of the human rib cage. The

spine incorporates flexible joints in the thoracic and lumbar spine, allowing dynamic spine flexion as well as static adjustment in the neck and lumbar spine to accommodate seating in various postures. The upper leg has a compressive element in the femur and the lower leg has a compressive element in the tibia and an Achilles tendon load path to achieve human-like impact response. The biofidelity of the THOR-50M has been assessed in a wide array of both component and full-body test conditions for which human response is known and was found to be both qualitatively and quantitatively congruent with human response corridors.

Improved instrumentation. The THOR-50M has both improved and additional instrumentation compared to the HIII-50M. The thorax instrumentation measures the three-dimensional deformation of the rib cage at four locations. The abdomen is also designed with a multi-point measurement system that monitors three-dimensional deformation of the abdomen at two locations. The upper leg includes an acetabulum load cell in the pelvis to measure load transfer from the femur to the hip. The lower leg has extensive instrumentation to support injury risk calculation.

Improved injury prediction. The biofidelity of the THOR-50M, combined with its extensive instrumentation, provides an enhanced capability to measure expected human response and predict injury. Injury criteria and injury risk functions, which relate instrumentation measurements to a predicted risk of human injury, have been developed for the head, neck, chest, abdomen, pelvis, upper leg, and lower leg of the THOR-50M.³⁴ These include injury criteria analogous to those currently specified for the HIII-50M in FMVSS No. 208 as well as injury criteria that are not currently specified for the HIII-50M in FMVSS No. 208. We believe this enhanced injury prediction capability will translate into restraint system designs that have the potential to enhance occupant protection. NHTSA and others, including vehicle manufacturers, have already taken advantage of these capabilities in the research arena.

Improved evaluation of vehicle performance. These enhancements allow the THOR-50M to better differentiate the performance of

different vehicles and restraint systems. The more sophisticated measurement capabilities of an advanced ATD are better suited to develop and test more sophisticated and highly tunable contemporary restraint systems with features such as multi-stage air bags and force-limiting/pre-tensioning seat belts. Motor vehicle manufacturers and restraint suppliers have already used the THOR-50M to evaluate vehicle crashworthiness and develop occupant protection countermeasures. Numerous conference and journal articles describing the use of the THOR-50M have been published. For example, in a study examining the performance of different restraint systems in frontal impact sled tests using both the THOR-50M and HIII-50M, the THOR-50M was found to be more sensitive to the restraint conditions, as it was able to differentiate between both crash severity and restraint performance.³⁵ Another study investigated a novel air bag system with three inflated chambers with a connected sail panel to promote earlier engagement with the occupant and prevent lateral motion and head rotation; sled testing using the THOR-50M demonstrated a reduction in brain injury risk due to head angular velocity, as quantified using the Brain Injury Criterion (BrIC).³⁶ Other studies have also implemented the THOR-50M to assess and develop restraint systems.³⁷

Adoption of the THOR-50M in Europe

In 2013, the European Commission (EC) issued a final report detailing the need for a new crash test dummy as a means to implement regulatory requirements for new vehicle safety technologies, particularly those technologies that reduce thorax injuries in frontal crashes.³⁸ At the time, the

³⁰ Part 572 THOR 5th Female Crash Test Dummy (RIN 2127-AM56), Spring 2023 Unified Agenda of Regulatory and Deregulatory Actions; Department of Transportation, available at <https://www.reginfo.gov/public/do/eAgendaViewRule?pubId=202304&RIN=2127-AM56>. This rulemaking would amend 49 CFR part 572 by adding design and performance specifications for a new test dummy known as the THOR-05F.

³¹ See Docket No. NHTSA-2019-0107, available at [regulations.gov](https://www.regulations.gov).

³² Data Sources: Fatality Analysis Reporting System (FARS): 2017-2020 Final File and 2021 Annual Report File (ARF); Report Generated: Wednesday, June 28, 2023 (12:48:52 p.m.); VERSION 5.6, RELEASED MAY 19, 2023

³³ Charles J. Kahane, *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*. 89 DOT HS 812 069 at 89, Department of Transportation, National Highway Traffic Safety Administration (2015).

³⁴ Craig, M., Parent, D., Lee, E., Rudd, R., Takhounts, E., Hasija, V. (2020). Injury Criteria for the THOR 50th Male ATD. *Regulations.gov* Docket ID NHTSA-2019-0106-0008, available at: <https://www.regulations.gov/document/NHTSA-2019-0106-0008>.

³⁵ Sunnevång, C., Hynd, D., Carroll, J., Dahlgren, M., "Comparison of the THORAX Demonstrator and HIII Sensitivity to Crash Severity and Occupant Restraint Variation," Proceedings of the 2014 IRCOBI Conference, Paper No. IRC-14-42, 2014.

³⁶ Hardesty, J. (2021). Next-Generation Passenger Airbag. SAE Government-Industry Digital Summit (oral only).

³⁷ See also, e.g., Hu, J., Reed, M. P., Rupp, J. D., Fischer, K., Lange, P., & Adler, A. (2017). Optimizing seat belt and airbag designs for rear seat occupant protection in frontal crashes (No. 2017-22-0004). SAE Technical Paper; Eggers, A., Eickhoff, B., Dobberstein, J., Zellmer, H., Adolph, T. (2014). Effects of Variations in Belt Geometry, Double Pretensioning and Adaptive Load Limiting on Advanced Chest Measurements of THOR and Hybrid III. Proceedings of the 2014 IRCOBI Conference, Paper No. IRC-14-40; Hu, J., Fischer, K., Schroeder, A., Boyle, K., Adler, A., & Reed, M. (2019, October). Development of oblique restraint countermeasures (Report No. DOT HS 812 814). Washington, DC: National Highway Traffic Safety Administration. Available at: <https://rosap.nhtl.bts.gov/view/dot/44143>.

³⁸ European Commission, Seventh Framework Programme, THORAX Project Final Report,

THOR-50M was envisioned as the best evaluation tool for this purpose. In 2015, United Nations Economic Commission for Europe (UNECE) Regulation No. 137 (R137) went into effect. R137 specifies a 50 km/h, full-width rigid barrier frontal impact test with driver and passenger HIII-50M and HIII-5F dummies respectively. One objective of the regulation was to encourage better restraint systems across a wider range of collision severities.³⁹

In 2017, an ECE-funded study found that the R137 condition and dummy diversity were not sufficiently different to existing UN Regulation No. 94 (R94) to force improvements in restraint systems. R94 involves a 56 km/h frontal offset test which also prescribes the HIII-50M in the driver and right front seat. To deliver the expected benefits, the 2017 final report recommended implementation of the THOR-50M in R137 as a replacement for the HIII-50M.⁴⁰ The THOR-50M was recognized as being more biofidelic in its representation of thoracic response and prediction of thorax injuries, which are the key serious and fatal injury types in full-width collisions targeted by R137.

In 2018, the EC published a report on the cost-effectiveness and the number of future injuries and fatalities that could be prevented at a European level for different sets of vehicle safety measures.⁴¹ Several new sets of safety measures were considered for mandatory implementation in new vehicles starting from 2022. This included the introduction of the THOR-50M into R137. The THOR-50M was considered for inclusion in a program titled “Full-width Frontal Occupant Protection with THOR (FFW-THO),” which would lower injury criteria thresholds to encourage implementation of adaptive restraints. It was envisioned that the implementation of the THOR-50M would result in an initial cost of 16

Euros per vehicle, for vehicles that currently comply with UN Regulation No. 137 with Hybrid III ATDs but not with THOR-50M ATDs. It was estimated that vehicles that comply with FFW-THO would provide a 6% increase in effectiveness in protecting against serious injuries compared to vehicles that comply with R137 alone.

In 2019, the EC presented work priorities to WP.29⁴² for 2019–2021 for UNECE activities. An amendment to introduce the THOR-50M into R137 was included. The target date for a WP.29 vote was listed as Q4/2021.⁴³ In 2020, Japan and the EC jointly initiated discussions within WP.29 to establish a priority for the new task. In preparation for an eventual adoption into R137, the E.C. commissioned TRL (Transport Research Laboratory, UK)⁴⁴ to conduct a survey of various stakeholders on the readiness of the THOR-50M. ATD manufacturers, crash test laboratories, and crash safety research laboratories were consulted. The results of the survey are contained within Annex 7 of a broader report on general safety regulations, published by the E.C. in 2021.⁴⁵ In the E.C. report, there are a number of recommendations based on stakeholder feedback. They include revisions to the dummy design and qualification procedures that may be needed prior to adopting THOR-50M into M.R. 1⁴⁶ and R137. Most stakeholders recommended the formation of either an Informal Working

Group or a Technical Evaluation Group under the umbrella of UNECE WP.29 to co-ordinate this activity. As of May 2023, a WP.29 working group has yet to be established and timelines for amendments to R137 and M.R. 1 are undetermined. The areas for further investigation identified in Annex 7 are discussed in this NPRM.

Although the ECE has not yet officially adopted the THOR-50M, the European New Car Assessment Programme (Euro NCAP) has been rating vehicles using the dummy. Euro NCAP has implemented a moving progressive deformable barrier (MPDB) frontal impact testing protocol with a THOR-50M in the driver’s seat.⁴⁷ The THOR-50M used by Euro NCAP is specified in Technical Bulletin 026 (TB026)⁴⁸ “THOR Specification and Certification.” TB026 explicitly adopts—with some variations—NHTSA’s 2018 technical data package (*i.e.*, the 2018 drawing package,⁴⁹ qualification procedures,⁵⁰ and PADI⁵¹). The variations to the 2018 technical data package are relatively limited. For example, TB026 specifies an onboard (in-dummy) data acquisition system and a variation to the adjustable spine to facilitate data acquisition system (DAS) installation; minor deviations in the shoulder assembly; and the use of the HIII-50M lower legs. These modifications are discussed in more detail in the relevant sections of the preamble and are summarized in Section IX, Consideration of alternatives. NHTSA’s understanding is that no regulatory authorities or third-party vehicle rating programs other than Euro NCAP currently specify the THOR-50M for use in vehicle crash tests.

Motor vehicle and equipment manufacturers’ interest in the design and operation of the THOR-50M has been heightened since the dummy was introduced into Euro NCAP and plans for R137 were announced. Discussions are taking place within International Standards Organization (ISO) Technical Committee 22 (Road Vehicles), Subcommittee 36 (Safety and impact testing), Working Group 5 (Anthropomorphic test devices) for

Thoracic injury assessment for improved vehicle safety, 1/7/2013.

³⁹ Seidl, M., Edwards, M., Barrow, A., Hynd, D., & Broertjes, P. (2017). The Expected Impact of UN Regulation No. 137 Tests on European Cars and Suggested Test Protocol Modifications to Maximise Benefits. In 25th International Technical Conference on the Enhanced Safety of Vehicles (ESV).

⁴⁰ Seidl, M., Hynd, D., McCarthy, M., Martin, P., Hunt, R., Mohan, S., Krishnamurthy, V. and O’Connell, S.: TRL Ltd. (2017). In depth cost-effectiveness analysis of the identified measures and features regarding the way forward for EU vehicle safety, Final Report, ISBN 978-92-79-68704-4, European Commission, 08-31-2017.

⁴¹ Seidl, M., Khatri, R., Carroll, J., Hynd, D., Wallbank, C., Kent, J. (2018) Cost-effectiveness analysis of Policy Options for the mandatory implementation of different sets of vehicle safety measures—Review of the General Safety and Pedestrian Safety Regulations, Technical Annex to GSR2 report SI2.733025.

⁴² This was a thrice-annual briefing on the regulatory status within the various working parties under WP.29’s World Forum for Harmonization of Vehicle Regulations, including the status of R137 under the Working Party for Passive Safety (GRSP).

⁴³ WP.29-177-18, 177th WP.29, 12-15 March 2019, EU Work priorities for 2019–2021 for UNECE activities.

⁴⁴ TRL serves as an independent advisory to the E.C. TRL’s report was performed under contract with the European Commission (E.C.), who sought to update the General Safety Regulation for Europe to include new and developing technologies with the aim of reducing Europe’s annual road fatalities. The report reflects TRL’s recommendations for consideration by the E.C.

⁴⁵ General Safety Regulation: Technical study to assess and develop performance requirements and test protocols for various measures implementing the new General Safety Regulation, for accident avoidance and vehicle occupant, pedestrian and cyclist protection in case of collisions, Final Report, March 2021, Publications Office of the EU (europa.eu), ISBN 978-92-76-08556-0, DOI 10.2873/499942, Catalogue number, ET-04-19-467-EN-N. <https://op.europa.eu/en/publication-detail/-/publication/6987b729-a313-11eb-9585-01aa75ed71a1/language-en/format-PDF/source-217672351> (last accessed 5/25/2023).

⁴⁶ Mutual Resolution No. 1 (M.R.1) of the 1958 and the 1998 Agreements. Concerning the description and performance of test tools and devices necessary for the assessment of compliance of wheeled vehicles, equipment and parts according to the technical prescriptions specified in Regulations and global technical regulations, ECE/TRANS/WP.29/1101, 10 January 2013.

⁴⁷ European New Car Assessment Programme (2022). MPDB Frontal Impact Testing Protocol, Version 1.1.3, available at: <https://www.euroncap.com/en/for-engineers/protocols/adult-occupant-protection/>.

⁴⁸ European New Car Assessment Programme (2023). THOR Specification and Certification, Version 1.3, available at: <https://www.euroncap.com/en/for-engineers/supporting-information/technical-bulletins/>.

⁴⁹ § 1.1.

⁵⁰ § 2.1.

⁵¹ § 3.1.

modifications suggested by manufacturers. With no defined European entity to maintain configuration control, ISO has enlisted Humanetics Innovative Solutions, Inc. (Humanetics) to investigate its change recommendations directly. In particular, discussions have taken place regarding modifications to the shoulder pad and rib guide. These modifications are discussed in the relevant sections of the NPRM.

Need for This Rulemaking

NHTSA expects a variety of benefits from incorporating the THOR-50M in Part 572. The THOR-50M is an advanced dummy with many advantages over existing dummies with respect to biofidelity, instrumentation, and injury prediction. NHTSA believes that the THOR-50M's enhancements will lead to more effective restraint system designs and more informative comparisons of the safety of different vehicles. Euro NCAP has adopted it, the ECE is considering it for use in R137, and it is likely being used by vehicle and restraint manufacturers for testing, research, and development. Therefore, we believe vehicle manufacturers would choose to certify new vehicles using the THOR-50M if given the option, because this would enable manufacturers to streamline testing by using the same dummy for research and development and to verify compliance and vehicle ratings. NHTSA is therefore also considering a proposal to amend FMVSS No. 208 to give vehicle manufacturers the option of selecting the THOR-50M for use in belted and unbelted crash testing instead of the HIII-50M.⁵²

There would be other benefits as well. For instance, the THOR-50M is well-suited for the types of new seating configurations brought on by vehicles with Automated Driving Systems (ADS). NHTSA is developing an adaptation of the THOR-50M that is better suited for reclined postures which may be prevalent among ADS occupants.⁵³

⁵² FMVSS No. 208 THOR-50M Compliance Option (RIN 2127-AM21), Fall 2023 Unified Agenda of Regulatory and Deregulatory Actions; Department of Transportation, available at <https://www.reginfo.gov/public/do/eAgendaViewRule?publd=202304&RIN=2127-AM21>. This rulemaking would propose injury assessment reference values for the THOR-50M comparable to the IARVs currently specified for the HIII-50M.

⁵³ Forman, J., Caudillo-Huerta, A., McMahon, J., Panzer, M., Marshall, W., Winter, D., Dyer, M., Lemmen, P. (2021). Modifications to the THOR-50M for Improved Usability in Reclined Postures—Update and Preliminary Findings. 2021 SAE Government-Industry Digital Summit, available at: <https://www.nhtsa.gov/node/103691>. The adaptation to the THOR-50M design for use in

NHTSA's test dummies are also used in a range of applications beyond FMVSS compliance testing—such as NCAP testing, standards and regulations in other transportation modes, and research. While the purpose of Part 572 is to describe the anthropomorphic test devices that are to be used for compliance testing of motor vehicles and motor vehicle equipment with motor vehicle safety standards,⁵⁴ it also serves as a definition of the ATD for other purposes, such as consumer information crash testing, standards and regulations in other transportation modes, and research. As such, it would be to the benefit of government, academia, and the multi-modal transportation industry to include a definition of the THOR-50M ATD in Part 572.⁵⁵

III. Design, Construction, and Instrumentation

In this section we discuss the anthropometry, design, construction, and instrumentation of the THOR-50M.

A. Anthropometry

The THOR-50M is a physical model of a 50th percentile male motor vehicle occupant. It is intended for use in the development and evaluation of vehicle safety countermeasures and vehicle safety performance in frontal crash tests. To ensure that the dummy responds in a human-like manner in a vehicle crash environment, it is necessary that the size and shape of the dummy, referred to as anthropometry, provide an accurate representation of a mid-sized male. The anthropometry of the THOR-50M is based on a study by the University of Michigan Transportation Research Institute that documented the anthropometry of a mid-sized (50th percentile in stature and weight) male occupant in an automotive seating posture (AMVO study).^{56 57} This study

reclined seating environments is outside of the scope of this Part 572 NPRM.

⁵⁴ 49 CFR 572.1.

⁵⁵ For example, American Public Transportation Association standard APTA PR-CS-S-018-13 Rev. 1 describes the use of a THOR ATD in the testing of fixed workstation tables in passenger rail cars. American Public Transportation Association. (2015, October). Fixed Workstation Tables in Passenger Rail Cars. PR-CS-S-018-13, Rev. 1. Washington, DC, available at: https://www.apta.com/wp-content/uploads/Standards_Documents/APTA-PR-CS-S-018-13-Rev-1.pdf.

⁵⁶ Schneider, L.W., Robbins, D.H., Pflug, M.A., Snyder, R. G., "Development of Anthropometrically Based Design Specifications for an Advanced Adult Anthropomorphic Dummy Family; Volume 1- Procedures, Summary Findings and Appendices." U.S. Department of Transportation, DOT-HS-806-715, 1985.

⁵⁷ Robbins, D.H., "Development of Anthropometrically Based Design Specifications for an Advanced Adult Anthropomorphic Dummy

defines an average male as 76.57 kg (168.8 lb) in weight with a standing height of 175.1 cm (68.9 in). The AMVO study is currently internationally accepted as the standard anthropometry for the 50th percentile male ATD. The THOR-50M has a mass of 77.37 kg (170.6 lb) and a seated height of 101.8 cm (40.2 in). The standing height of the ATD cannot be measured since the pelvis does not allow a full standing posture; however, since it was developed using the AMVO body segment geometry and seated anthropometry, it is assumed that the stature of the THOR-50M is also 175.1 cm.

The THOR-50M is consistent with the AMVO anthropometry. NHTSA compared the dimensions of a representative dummy (S/N 9798) with the AMVO target dimensions (Table 1).⁵⁸ The AMVO procedure originally used to collect measurements from volunteers was adapted to collect the same or similar measurements on the THOR-50M.⁵⁹ Most of these measurements were taken with the THOR-50M seated on the AMVO bench, which has an angled seat and backrest. One adaptation was necessary to collect leg measurements on the AMVO bench: the THOR-50M has an integrated molded shoe that cannot be separated from its foot, while the AMVO data were collected on barefoot volunteers. To remedy this situation, the THOR-50M measurements were recorded after removing the entire molded shoe assembly and positioning the center of the ankle joint at the same location as the AMVO ankle landmark. Another adaptation was that four of the measurements were collected with the THOR-50M seated on a 90-degree bench, as specified on drawing 472-0000, Sheet 4. NHTSA also compared

Family; Volume 2-Anthropometric Specifications for mid-Sized Male Dummy; Volume 3-Anthropometric Specifications for Small Female and Large Male Dummies," U.S. Department of Transportation, DOT-HS-806-716 & 717, 1985.

⁵⁸ A THOR-50M unit is a collection of serialized parts that can be swapped out with other dummies, so is not considered a "serialized" dummy. Indeed, many of the subassemblies that were part of S/N 9798 when NHTSA took these measurements were subsequently swapped out of the dummy. See Section VII.A.

⁵⁹ These AMVO measurements were collected as an assessment of anthropometry; it is understood that there is variation in initial position and measurement methodology that prevents the use of such measurements as a repeatable dimensional assessment. In practice, a simplified set of dimensional requirements are put in place as a check for overall part fit, tolerance stack, and to ensure that the dummy is assembled correctly. These requirements are specified on drawing 472-0000, Sheet 4, and are collected following the "Procedures for Measuring External Dimensions" section of the PADI.

the body segment masses specified in the proposed THOR drawing package (472-0000, Sheet 5) with the AMVO body segment masses (Table 2), and the masses were also consistent.

TABLE 1—THOR-50M ANTHROPOMETRY COMPARED TO AMVO

Dimensions (all measurements in centimeters)	AMVO target (Robbins et al 1983)	THOR-50M S/N 9798
Height of top of head to floor	100.3	101.8
Height of shoulder to floor	72.1	74.2
H-point to knee joint distance (note 1)	43.2	42.3
Buttock to knee end distance (note 2)	59.3	62.0
Height of knee from floor	45.3	47.0
Head circumference	57.1	58.7
Head top-chin distance	19.7	22.9
Head breadth	15.8	15.3
Chest circumference	101.1	95.5
Chest breadth	34.9	30.9
Chest depth (note 3)	22.7	22.4
Abdomen circumference	91.3	99.0
Abdomen breadth	32.5	32.5
Abdomen depth (note 2)	26.9	29.8
Pelvis breadth	38.5	38.8
Thigh max circumference	57.9	56.8
Thigh max breadth	19.4	17.1
Mid thigh circumference	50.4	56.0
Mid thigh breadth	15.5	17.8
Calf circumference	37.3	37.5
Calf breadth	11.0	9.1
Calf depth	11.8	11.9

¹ THOR-50M specified on 472-0000, Sh. 4, measurement F (Knee Pivot to Hip Pivot) as seated upright on a 90-degree bench.

² THOR-50M and AMVO measured as seated upright on a 90-degree bench.

³ THOR-50M specified on 472-0000, Sh. 4, measurement I (Rib #3 depth) as seated upright on a 90-degree bench without jacket installed.

TABLE 2—THOR-50M BODY SEGMENT MASSES COMPARED TO AMVO

Body segment masses (all measurements in kilograms)	AMVO target (Robbins et al 1983)	THOR-50M specification *
Head	4.137	4.501
Neck	** (4.55)	
Thorax	0.965	2.363
Lower Abdomen	23.763	23.517
Pelvis	2.365	2.664
Upper Arm, Left or Right	11.414	15.229
Lower Arm with Hand, Left or Right	1.769	1.701
Upper Leg, Left or Right	2.022	2.227
Lower Legs, Left or Right	8.614	5.618
Feet, Left or Right including shoe	3.587	3.396
	*** 1.551	1.604
Total Weight	76.562	77.366

* Listed on Drawing No. 472-0000, Sh. 5.

** Mass reported in Melvin JW, Weber, K. "Task B Final Report: Review of Biomechanical Impact Response and Injury in the Automotive Environment," U.S. Department of Transportation, DOT-HS-807-042, 1985. The AMVO target is believed to be too low.

*** This adds the mass of a size 11 Oxford shoe (0.57 kg) specified for use in FMVSS No. 208 for the HIII-50M) to the AMVO specification of 0.981 kg so as to be comparable to the THOR's foot-within-a-molded-shoe mass.

B. Technical Data Package

The construction of the THOR-50M is similar to other ATDs currently defined in Part 572, with a metallic frame largely covered in urethane and/or vinyl representing flesh; body segments connected by translational and rotational joints; and deformable rubber or foam elements to prevent hard contact between metallic surfaces and to provide human-like impact response.

The kinematic and dynamic biomechanical performance requirements of the THOR-50M were developed based on post-mortem human subject (PMHS) and volunteer response data, described in Section IV, Biofidelity.

The THOR-50M that we are proposing in this NPRM is the version defined in the 2023 technical data package (consisting of two-dimensional

engineering drawings and a Parts list; procedures for assembly, disassembly, and inspection (PADI); and qualification procedures). The 2023 technical data package also includes an addendum with the drawings and drawing/parts list for an alternate configuration with an in-dummy data acquisition system, as discussed in Section III.N, Data Acquisition System. It is anticipated that, upon finalization of this proposal,

the in-dummy DAS drawings will be fully integrated within the relevant technical data package components. The technical data package is summarized in Table 3. For these documents, the NPRM cites to the document location in the research docket. NHTSA is not placing copies of these documents in the rulemaking docket, in order to avoid

potential confusion from having identical documents docketed at different times in different dockets. However, NHTSA intends these to be included as part of the rulemaking record. A memo explaining this is also being included in the rulemaking docket. In addition, as noted in the background section, NHTSA began

publishing the technical data package to its website starting in 2015. The 2023 technical data package updates the 2018 technical data package. These updates were made to address typographical errors, improve clarity, and add alternative design elements. Table 4 summarizes these updates.

TABLE 3—THOR—50M TECHNICAL DATA PACKAGE

Title	Link
THOR 50th Percentile Male with Alternate Shoulders Frontal Crash Test Dummy Drawings, External Dimensions, and Mass Properties.	https://www.regulations.gov/document/NHTSA-2019-0106-0013 .
*THOR—50M DAS Integration Kit Drawings, April 2023	https://www.regulations.gov/document/NHTSA-2019-0106-0019 .
*Parts List, THOR—50M DAS Integration Kit, April 2023	https://www.regulations.gov/document/NHTSA-2019-0106-0018 .
Parts List, THOR 50th Percentile Male Frontal Crash Test Dummy with Alternate Shoulders.	https://www.regulations.gov/document/NHTSA-2019-0106-0015 .
THOR 50th Percentile Male (THOR—50M): Procedures for Assembly, Disassembly, and Inspection (PADI): June 2023.	https://www.regulations.gov/document/NHTSA-2019-0106-0017 .
THOR 50th Percentile Male (THOR—50M) Qualification Procedures and Requirements, April 2023.	https://www.regulations.gov/document/NHTSA-2019-0106-0010 .

* The DAS Integration Kit drawings and drawing/parts list would not themselves be incorporated by reference into Part 572. It is anticipated that, upon finalization of this proposal, these documents will be fully integrated within the relevant technical data package components.

TABLE 4—SUMMARY OF UPDATES MADE IN THE 2023 THOR—50M TECHNICAL DATA PACKAGE

Technical Data Package Element	Revisions in 2023 Version
Drawing Package	Includes drawings for alternate shoulder, removal of notes suggesting that qualification specifications supersede drawing specifications, and changes to correct typographical drawing errors. Complete change log found in “THOR—50th Percentile Male with Alternate Shoulders (THOR—50M w/ALT. SHOULDERS) Drawing Revisions”. ⁶⁰
PADI	Minor typographical changes; complete change log found in Section 20 of “THOR 50th Percentile Male (THOR—50M) Procedures for Assembly, Disassembly, and Inspection (PADI)”.
Qualification Procedures	Revised upper leg qualification test mode, adjusted language to be more prescriptive, removed unit conversions, and corrected typographical errors. Complete change log found in Appendix B of “THOR 50th Percentile Male (THOR—50M) Qualification Procedures and Requirements, April 2023”.

Below we briefly discuss several aspects of the technical data package in more detail.

Engineering Drawings and Parts List

The engineering drawings and parts list specify the configuration of the THOR—50M. Included in the drawings are the required dimensions and tolerances, material properties, and component or material testing requirements and associated specifications. In a few instances, the drawings specify quasi-static tests and/or performance requirements for individual parts (such as a compression or flexion test for a molded part or subassembly); however, passing a specified performance (or qualification) test is not an alternate criterion for accepting a part that deviates from the drawing specifications.⁶¹ All

instruments are specified by corresponding SA572-xxx drawings.⁶² SA drawings are included for associated mounts and hardware that are not otherwise needed when the dummy is configured with a corresponding structural replacement. Brand name call-outs are only used for parts and materials that have widespread availability and are used for a wide variety of non-ATD applications. It includes materials widely identified by their tradenames, such as Teflon, Acetal, Lexan, and Nitinol. Call-outs are also used for bonding agents, fasteners,

and other items that are also widely available for non-ATD applications.

are reflected in the proposed 2023 technical data package. In cases where some flexibility is allowed in order to meet the qualification specification, a “REF.” prefix is added to specific dimensions or material specifications.

⁶² This convention is used for all instruments on all Part 572 dummies. SA572 simply indicates that it is an instrument, and Sxx is the next-in-line number assigned by NHTSA to the instrument. Some load cells (and part numbers) are used on different Part 572 subpart dummies. For THOR, this applies to SA572-S4 (accelerometer) which is used on many other dummies.

In some instances, the drawing package permits two different part or instrumentation configurations that are both fully specified. For example, the head accelerometer mounting plate assembly drawing (472-1200) calls out three different angular rate sensors (SA572-S56, SA572-S57, or SA572-S58) which may be desired by the end user depending on the implementation of the ATD.⁶³ In the sections below on specific body regions we discuss the proposed as well as alternate designs and instrumentations that are not included in the proposed specifications but which we are considering specifying in the final rule and on which we are seeking comment. If NHTSA were to use the dummy for FMVSS compliance testing, NHTSA could test with any alternative configurations at its own discretion. Thus, the IARVs would have

⁶³ Similar situations exist with currently federalized ATDs, such as the HIII-10C, where either a chest slider pot or an IR-TRACC is permissible.

⁶⁰ See Table 5.

⁶¹ In the drawings which were part of the August 2018 technical data package, several notes state that “qualification takes precedence over design.” These notes were unintentionally carried over from earlier drawing versions used during THOR—50M development, and have since been removed. These

to be met using a dummy with any permissible configuration. Manufacturers are not required to test their products in any particular manner, as long as they exercise due care that their products will meet the requirements when tested by NHTSA under the procedures specified in the standard, including the relevant dummy specified in Part 572.⁶⁴ However, a

manufacturer would not be able to claim that a vehicle fully complies with a standard if it meets the standard’s requirements in only one of the dummy’s configurations, but not the other.

In addition to the engineering drawings that would be incorporated by reference, we are also providing supplemental documentation on the

form and function of the THOR–50M. These reference materials are summarized in Table 5. These files would not be incorporated by reference in Part 572 and would therefore not be part of the THOR–50M specification. Instead, they are intended only for reference purposes (e.g., to facilitate fabrication and inspection of parts with intricate geometries).

TABLE 5—THOR–50M DESIGN REFERENCE DOCUMENTATION

Title	Link
THOR–50M Drawing Package—2D AutoCAD Jan 2023	https://static.nhtsa.gov/nhtsa/downloads/THOR_50M_Drawing_Package/NPRM/THOR-50M%20with%20Alternate%20Shoulders%20Jan%202023-AutoCAD%20DWG%20Files.zip
THOR–50M Drawing Package—3D Inventor Format Jan 2023	https://static.nhtsa.gov/nhtsa/downloads/THOR_50M_Drawing_Package/NPRM/THOR-50M%20with%20Alternate%20Shoulders%20Jan%202023-Inventor%20Files.zip
THOR–50M Drawing Package—3D STEP Format Jan 2023	https://static.nhtsa.gov/nhtsa/downloads/THOR_50M_Drawing_Package/NPRM/THOR-50M%20DAS%20Integration%20Kit-3D%20STEP%20Files_April%202023.zip
THOR 50th Percentile Male with Alternate Shoulders Drawing Revisions, Jan 2023.	https://www.regulations.gov/document/NHTSA-2019-0106-0014
THOR–50M DAS Integration Kit—2D AutoCAD, April 2023	https://static.nhtsa.gov/nhtsa/downloads/THOR_50M_Drawing_Package/NPRM/THOR-50M%20DAS%20Integration%20Kit-AutoCAD%20DWG%20Files_April%202023.zip
THOR–50M DAS Integration Kit—3D STEP Format, April 2023	https://static.nhtsa.gov/nhtsa/downloads/THOR_50M_Drawing_Package/NPRM/THOR-50M%20DAS%20Integration%20Kit-3D%20STEP%20Files_April%202023.zip
THOR–50M DAS Integration Kit—Inventor Format, April 2023	https://static.nhtsa.gov/nhtsa/downloads/THOR_50M_Drawing_Package/NPRM/THOR-50M%20DAS%20Integration%20Kit-Inventor%20Files_April%202023.zip

The THOR–50M used by Euro NCAP is specified in Technical Bulletin 026, “THOR Specification and Certification.”⁶⁵ TB026 explicitly adopts—with some deviations—the 2018 drawing package.⁶⁶ These deviations in TB026 include specification of an onboard (in-dummy) data acquisition system and a variation to the adjustable spine to facilitate DAS installation; minor deviations in the shoulder assembly; and the use of the HIII–50M lower legs. These modifications are discussed in more detail in the relevant sections of the preamble, and are summarized in Section IX, Consideration of alternatives. Euro NCAP TB026 specifies the 2018 drawing package, while this proposal specifies the 2023 drawing package. However, given the differences described in Table 4 above, this deviation is likely to be inconsequential. The deviations TB026 makes to the 2018 drawing package are not accompanied by engineering drawings, which may tend to lessen the

dummy’s overall objectivity. Objectivity is a statutory necessity for ATDs in Part 572. While the lack of accompanying drawings for these deviations may be adequate for the Euro NCAP rating program, it could lead to a future population of THOR–50M units that are sufficiently non-uniform as to render them unsuited for FMVSS applications.

PADI

The PADI provides step-by-step procedures on how to properly assemble the dummy. This includes instructions on part alignment, torque settings, wire routings, and other adjustments that are not otherwise described in the engineering drawings. The PADI provides explicit installation instructions for all instruments. Euro NCAP TB026 specifies the 2018 PADI,⁶⁷ while this proposal specifies the 2023 PADI. However, the differences between the 2018 PADI and 2023 PADI are primarily corrections to typographic errors, so this deviation is likely to be inconsequential. In some instances, the

drawing package permits two different part or instrumentation configurations that are (or will be in the final rule) both fully specified (for example, the IR–TRACC and the S-Track for the chest instrumentation). The proposed PADI does not currently contain installation instructions for the optional parts (e.g. alternate shoulder) or instrumentation (e.g., the S-Track). However, where multiple optional configurations are permitted and installation differences are non-trivial, NHTSA anticipates supplementing the PADI with such instructions in the final rule.

Qualification Procedures

The qualification procedures describe a series of impact tests performed on a fully assembled dummy or sub-assembly. NHTSA has established numeric bounds or acceptance intervals for the ATD responses in these tests. The qualification procedures are discussed in Section V.

⁶⁴ See, e.g., 38 FR 12934, 12935 (May 17, 1973) (“Manufacturers should understand that they are not required to test their products in any particular manner, as long as they exercise due care that their products will meet the requirements when tested by

the NHTSA under the procedures specified in the standard.”).

⁶⁵ European New Car Assessment Programme (2023). THOR Specification and Certification, Version 1.3, available at: [https://](https://www.euroncap.com/en/for-engineers/supporting-information/technical-bulletins/)

www.euroncap.com/en/for-engineers/supporting-information/technical-bulletins/.

⁶⁶ § 1.1.

⁶⁷ § 3.1.

Summary

NHTSA believes that the technical data package adequately describes and would ensure the uniformity of the dummy. Upon finalization of this proposal, a new subpart for the THOR-50M would be added to Part 572, and the technical data package documents would be incorporated by reference.

NHTSA seeks comment on whether the dummy is sufficiently specified to ensure that dummies are uniform such that they will provide repeatable and reproducible measurements. We also seek comment on whether it would be useful to end-users of the dummy if NHTSA created a list of suppliers used by NHTSA to obtain various parts and instrumentation, and/or general specifications or operating characteristics of a part (as provided by a manufacturer's specification sheet). Such documentation would not be incorporated into Part 572 but would be provided as a reference aid for users and could be periodically updated by NHTSA.

C. Head and Face

The head of the THOR-50M is primarily constructed of a cast aluminum skull covered in a urethane head skin. It includes two features not seen on the HIII-50M: spring towers and a featureless face. The spring towers are integral to the response of the head/neck system, as they are the mounting location of the cables that represent the musculature of the neck (described further in the following section). The head is equipped with three uniaxial accelerometers and three angular rate sensors at the head center of gravity (CG) to measure translational acceleration and angular velocity, respectively. The head also includes a biaxial tilt sensor which measures the quasi-static orientation of the head for pre-test positioning purposes.

The face is constructed of an open-cell urethane foam sandwiched between the head skin and the face load distribution plates. The featureless face allows for more repeatable and reproducible interactions with potential contact surfaces and meets enhanced biomechanical response requirements which have not been implemented on any existing ATDs. Additionally, the face can be configured with five uniaxial load cells: left and right eye, left and right cheek, and chin.⁶⁸

⁶⁸ These load cells have not been used in any tests currently available in NHTSA's Vehicle or Biomechanics databases, and are typically replaced with structural replacements during testing. While the THOR-50M Qualification Procedure does include a face impact test which would exercise the

D. Neck

The neck of the THOR-50M is visibly and functionally different than the ATDs currently defined in Part 572. While typical ATD designs use only a pin joint between the base of the head and the upper neck load cell, the THOR-50M neck is connected to the head via three separate load paths: two cables (one anterior and one posterior) and a pin joint between the base of the head and the upper neck load cell. These load paths are independently instrumented, allowing the isolation of forces and moments on the components representing bone and ligament from the components representing muscles. This is expected to allow for improved injury prediction for the cervical spine because the abbreviated injury scale (AIS) 2+ injuries⁶⁹ to the cervical spine in motor vehicle crashes are most commonly fractures, so the ability to measure forces and moments acting on the bones and ligaments separately from the forces acting through the musculature allows a more accurate prediction of these fractures.⁷⁰

The biomechanical basis of the THOR-50M neck design is well-established.^{71 72} The construction of the THOR-50M neck allows the head to initially rotate relatively freely in the fore and aft directions. This allows the head/neck assembly to demonstrate the phenomenon known as head lag demonstrated by human volunteers in restrained frontal loading conditions, where the rotation of the head is delayed relative to the rotation of the neck.⁷³ This phenomenon results from the head initially translating forward with respect to the base of the neck,

face load cells if installed, there are currently no qualification specifications on face load cell forces.

⁶⁹ The Abbreviated Injury Scale (AIS) ranks individual injuries by body region on a scale of 1 to 6: 1=minor,

2=moderate, 3=serious, 4=severe, 5=critical, and 6=maximum (untreatable).

⁷⁰ Craig, M., Parent, D., Lee, E., Rudd, R., Takhounts, E., Hasija, V. (2020). Injury Criteria for the THOR 50th Male ATD. Docket ID NHTSA-2019-0106-0008, available at: <https://www.regulations.gov/document/NHTSA-2019-0106-0008>.

⁷¹ White RP., Zhou Y., Rangarajan N., Haffner M., Eppinger R., Kleinberger M., "Development of an Instrumented Biofidelic Neck for the NHTSA Advanced Frontal Test Dummy," The 15th International Technical Conference on the Enhanced Safety of Vehicles, Paper No. 96-210-W-19, 1996.

⁷² Hoofman, M., van Ratingen, M., and Wisman, J., "Evaluation of the Dynamic and Kinematic Performance of the THOR Dummy: Neck Performance," Proceeding of the International Conference on the Biomechanics of Injury (IRCOBI) Conference, pp. 497-512, 1998.

⁷³ Thunnissen, J., Wisman, J., Ewing, C.L., Thomas, D.J. (1995) Human Volunteer Head-Neck Response in Frontal Flexion: A New Analysis. 39th Stapp Car Crash Conference, SAE Paper # 952721.

which is attached to the restrained torso. The change in angle of the head initially lags the change in angle of the line between the head and the neck but catches up by the time of peak excursion.

The instrumentation in the neck assembly includes spring load cells which measure the compression at the anterior and posterior spring locations, six-axis load cells at the top and base of the neck to measure the forces and moments developed at these locations, and a rotary potentiometer at the occipital condyle pin to measure the relative rotation between the head and top of the neck. Due to the multiple load paths of the neck, comparing THOR-50M neck forces and moments to traditional single-load-path ATD designs is not straightforward; the THOR-50M instrumentation would require post-processing⁷⁴ to represent the total neck forces and moments in order to compare to the upper neck load cell measurements of a HIII-50M ATD. However, as described in the THOR-50M Injury Criteria Report,⁷⁵ post-processing of the neck for calculation of neck injury risk is not necessary.

E. Chest

Throughout the development of the THOR-50M ATD, specific attention was given to the human-like response and injury prediction capability of the chest. Below we discuss the design and instrumentation of the THOR-50M chest.

1. Design

The THOR-50M's rib cage geometry is more realistic than the HIII-50M because the individual ribs are angled downward to better match the human rib orientation.⁷⁶ Biomechanical response requirements were selected to ensure human-like behavior in response to central chest impacts, oblique chest impacts, and steering rim impacts to the

⁷⁴ GESAC, Inc (2005). Users Manual: THOR Instrumentation Data Processing Program, Version 2.3; Appendix C: Procedure for Calculating Head Loads at the Occipital Condyle from Neck Load Cell Measurements. National Highway Traffic Safety Administration. Available at: <https://one.nhtsa.gov/DOI/NHTSA/NVS/Biomechanics%20&%20Trauma/THOR-NT%20Advanced%20Crash%20Test%20Dummy/THORTEST.zip>.

⁷⁵ Craig, M., Parent, D., Lee, E., Rudd, R., Takhounts, E., Hasija, V. (2020). Injury Criteria for the THOR 50th Male ATD. Docket ID NHTSA-2019-0106-0008, available at: <https://www.regulations.gov/document/NHTSA-2019-0106-0008>.

⁷⁶ Kent, R., Shaw, C.G., Lessley, D.J., Crandall, J.R. and Svensson, M.Y., "Comparison of Belted Hybrid III, THOR, and Cadaver Thoracic Responses in Oblique Frontal and Full Frontal Sled Tests," Proc. SAE 2003 World Congress. Paper No. 2003-01-0160, 2003.

rib cage and upper abdomen.⁷⁷ Better chest anthropometry means that the dummy's interaction with the restraint system is more representative of the interaction a human would experience.

The design of the THOR-50M includes a part known as a rib guide (472-3310) which is intended to prevent excessive downward motion of the anterior thorax during an impact. The rib guide is attached to the shoulder, and when there is downward motion of the ribs, the bottom of the rib damping material on rib #1 (the superior-most rib in the torso, 472-3310) can contact the top of the rib guide. Over time, this can result in an indent in the rib damping material. This indent has been observed on NHTSA-owned THOR-50M ATDs, but it has not been a concern as this is a sign of the rib guide performing its intended function. While this indent is not included on the drawing package, it is understood that an indent is acceptable as long as the qualification specifications (specifically, those of the upper thorax and lower thorax) are met, and it is not so deep that it allows metal-to-metal contact between the rib guide and the steel of the rib.

While Euro NCAP TB026 adopts the chest specified in the 2018 drawing package without any modifications, NHTSA is aware of two potential changes that have been discussed. Both of these changes appear to be intended to help ensure that the dummy is able to meet the upper thorax qualification response requirements. (The TB026 upper thorax qualification response requirements differ in a few ways from the proposed qualification requirements. This is discussed in more detail in Section V, Qualification Tests.)

The first change that has been discussed is a shorter rib guide. Humanetics Innovative Solutions, Inc. (Humanetics) reported to ISO WG5 (in June 2020) that while the indent on the damping material has been a known issue since the THOR-NT, it has led to concerns because it leads to issues meeting the Euro NCAP upper thorax qualification response requirements (specifically, the Z-axis upper rib deflection requirement) on a consistent basis. Humanetics has therefore suggested the use of a new, shorter rib guide which would allow more Z-axis deflection—primarily in the upper

thorax qualification test, but presumably in other impact scenarios as well.

The second change is an additional rib performance specification. NHTSA is aware of a presentation made by the Japanese Automobile Manufacturers Association (in June 2020) to ISO WG5 describing an additional rib performance specification (*i.e.*, that would be specified in the drawing package) geared towards more consistently meeting the TB026 upper thorax qualification response requirements. The presentation included a procedure for an individual rib test using the same apparatus as the rib drop test for the ES-2re 50th percentile adult male side impact test dummy.⁷⁸ It noted data showing that the stiffness of the individual rib in the drop test was correlated with the thoracic impact response in the upper thorax qualification test condition.

NHTSA has tentatively decided not to implement either change. NHTSA's qualification testing of the dummy did not reveal any issues with meeting the proposed upper thorax qualification requirements, so we do not believe such changes are necessary. Moreover, before implementing the rib guide modification, it could be necessary to evaluate whether it would influence the dummy's response in biofidelity or thorax injury criteria test conditions. We do note, however, that the additional rib performance specification could be a useful way for ATD manufacturers to ensure that the fabricated ribs will result in an upper thorax qualification response consistent with upper thorax qualification specifications.

We seek comment on these issues. In particular, NHTSA requests comment from THOR-50M users who have evaluated alternative rib guide designs and have data to support equivalence of durability, repeatability and reproducibility, and equivalence of response in qualification, biofidelity, injury criteria, and vehicle crash test conditions.

2. Instrumentation

The THOR-50M is capable of measuring detailed information about how the chest responds in a crash. While the HIII-50M can measure chest deflection at only a single point (the sternum), the THOR-50M measures chest deflections at four points. This is useful because thoracic trauma imparted to restrained occupants does not always occur at the same location on the rib cage for all occupants in all frontal

crashes.⁷⁹ Measuring deflection from multiple locations has been found to improve injury prediction,⁸⁰ and can improve the assessment of thoracic loading in a vehicle environment with advanced occupant restraint technologies.⁸¹ While the HIII-50M measures the one-dimensional deflection at a single point, the THOR-50M can measure the three-dimensional position time-history for four points on the anterior rib cage relative to the local spine segment of rib origination, with two points on the upper chest, and two points on the lower chest. Between the upper and lower thorax instrumentation attachment points is a flexible joint (the Upper Thoracic Spine Flex Joint), so the reference coordinate system for the upper and lower thorax 3D motion measurements can change dynamically during a loading event. This instrumentation, coupled with its thoracic biofidelity,⁸² provides the THOR-50M ATD with the ability to better predict thoracic injuries and to potentially drive more appropriate restraint system countermeasures.⁸³

NHTSA is proposing to specify two deflection measurement devices, either of which NHTSA could choose, at its option, for use in the THOR-50M: the IR-TRACC and the S-Track.

IR-TRACC

The 2023 drawing package specifies a specific deflection measurement device, the Infrared Telescoping Rod for Assessment of Chest Compression (IR-

⁷⁹ Morgan, R.M., Eppinger, R.H., Haffner, M.P., Yoganandan, N., Pintar, F.A., Sances, A., Crandall, J.R., Pilkey, W.D., Klopp, G.S., Kallieris, D., Miltner, E., Mattern, R., Kuppa, S.M., and Sharpless, C.L., "Thoracic Trauma Assessment Formulations for Restrained Drivers in Simulated Frontal Impacts," Proc. 38th Stapp Car Crash Conference, pp. 15-34. Society of Automotive Engineers, Warrendale, PA., 1994.

⁸⁰ Kuppa, S., Eppinger, R., "Development of an Improved Thoracic Injury Criterion," Proceedings of the 42nd Stapp Car Crash Conference, SAE No. 983153, 1998 (data set consisting of 71 human subjects in various restraint systems and crash severities).

⁸¹ Yoganandan, N., Pintar, F., Rinaldi, J., "Evaluation of the RibEye Deflection Measurement System in the 50th Percentile Hybrid III Dummy." National Highway Traffic Safety Administration, DOT HS 811 102, March 2009.

⁸² Parent, D., Craig, M., Ridella, S., McFadden, J., "Thoracic Biofidelity Assessment of the THOR Mod Kit ATD," The 23rd Enhanced Safety of Vehicles Conference, Paper No. 13-0327, 2013.

⁸³ In addition to the deflection measurement system, the THOR-50M can also be instrumented with a uniaxial sternum accelerometer, triaxial accelerometers installed along the spine at the level of T1, T6, and T12, and a five-axis (three forces, two moments) load cell installed between the lumbar spine pitch change mechanism and the lumbar spine flex joint at the approximate anatomical level of T12. Clavicle loads cells can also be installed, but are not included in the THOR-50M described in the 2023 drawing package.

⁷⁷ National Highway Traffic Safety Administration, "Biomechanical Response Requirements of the THOR NHTSA Advanced Frontal Dummy, Revision 2005.1," Report No: GESAC-05-03, U.S. Department of Transportation, Washington, DC, March 2005. [http://www.nhtsa.gov/DOT/NHTSA/NVS/Biomechanics%20&%20Trauma/THOR-NT%20Advanced%20Crash%20Test%20Dummy/thorbio05_1.pdf].

⁷⁸ 49 CFR 572.185(b) Individual rib drop test.

TRACC).⁸⁴ The IR-TRACC improved on the previous deflection measurement systems (CRUX—Compact Rotary Unit; DGSP—Double Gimbaled String Potentiometer) in many ways. The 2023 drawing package specifies six IR-TRACCs: four in the thorax and two in the abdomen.⁸⁵ Each IR-TRACC measures the absolute point-to-point distance along its length; this is used in the calculation of thorax and abdomen compression. The IR-TRACC is attached to two rotational potentiometers; this enables measurement of the three-dimensional position of the anterior attachment point at the rib or front of the abdomen relative to the attachment point at the spine.

While NHTSA has generally been satisfied with the performance of the IR-TRACC, the experience of NHTSA and other users with IR-TRACC-equipped THOR-50Ms has revealed a few potential issues. Vehicle manufacturers have raised several concerns about the performance and durability of the IR-TRACC, such as having to frequently repair or replace IR-TRACCs, and problems with the abdomen IR-TRACCs.⁸⁶ And during NHTSA-sponsored testing (particularly in the frontal oblique crash test mode), NHTSA observed abrupt decreases in the IR-TRACC voltage time-history.⁸⁷ We believe this is noise (and not a signal) because it occurs in all IR-TRACC voltage channels of a single ATD at the same points in time. As explained later in this document (Section VII.B.2) and in Appendix F to the preamble,⁸⁸ NHTSA testing has shown that once the IR-TRACC voltage signal is linearized, scaled, filtered, and converted to three-dimensional deflection, this noise is no longer evident. Nonetheless, this presents a

risk of perceived or actual inaccuracies in thoracic and abdominal injury prediction during crash tests.

S-Track

In 2016 NHTSA issued a request for proposals for commercially-available devices capable of measuring the same or greater deflection range (roughly 90 millimeters of deflection for the thorax and 120 millimeters of deflection for the abdomen) within the same packaging space as the existing IR-TRACC devices.⁸⁹ Only one device—the S-Track—was identified. The S-Track, which is patented,⁹⁰ is produced by ATD-LabTech GmbH. (In 2022, Humanetics acquired ATD-LabTech.) Subsequent to the request for proposal, NHTSA also became aware of two additional deflection measurement devices: the KIR-TRACC, sold by Kistler Group, and the Spiral Track, sold by JASTI. NHTSA does not know whether these devices are congruent with the current THOR-50M parts and SA-drawings that describe the configuration and installation of IR-TRACCs. Because NHTSA became aware of these devices late in the development process (and neither was identified in NHTSA's request for proposals), they have not been considered for inclusion in the proposal, although NHTSA is considering evaluating whether they would be suitable instrumentation for the THOR-50M. Euro NCAP allows for installation of the IR-TRACC, the S-Track, and the KIR-TRACC.⁹¹

The S-Track is similar to the IR-TRACC in that it is in-dummy instrumentation that attaches to the same points in the dummy as the IR-TRACC. Both measure linear displacement, and when coupled with the gimbaled potentiometers, their signals can be post-processed to calculate three-dimensional motion. It differs in that the S-Track uses a mechanical scissor mechanism coupled to a linear potentiometer to measure linear motion along its axis, while the IR-TRACC uses a measurement of light transmittance, which requires a linearization calculation to estimate linear motion.

NHTSA has conducted a range of testing to evaluate the performance and equivalence of the S-Track. The testing, which included a partial qualification test series and sled tests, is briefly summarized below.⁹² A more detailed discussion of this material is available in a previously published paper (except, as noted below, the second set of sled tests, for which a report is forthcoming).⁹³

- The range and linearity of the S-Track and IR-TRACC sensors are comparable. The range of measurement of the S-Track is consistent with or larger than the range of measurement of the IR-TRACC, and all sensors were within the manufacturer's specification for the maximum allowable linear error as a percentage of full scale. This specification (0.5%) is tighter compared to the corresponding IR-TRACC specification (2%), though only one of the IR-TRACCs (right abdomen) showed a linearity error greater than 0.5%.

- Calibration and 3D static measurement assessments demonstrated similar or better accuracy compared to the IR-TRACC in the double-gimbal configuration for the upper left thorax, lower left thorax, and left abdomen. In the upper and lower thorax configurations, the S-Track showed less error than the IR-TRACC, and in the abdomen configuration, showed errors similar to the IR-TRACC.

- The form, fit, and function is comparable to the IR-TRACC. A full set of six S-Tracks was installed in a THOR-50M ATD. It did not present any connectivity or interference issues and appeared to be a plug-and-play replacement to the IR-TRACCs. One possible durability issue was identified

⁸⁴ Rouhana, S.W., Elhagediab, A.M., Chapp, J.J. "A high-speed sensor for measuring chest deflection in crash test dummies." Proceedings: International Technical Conference on the Enhanced Safety of Vehicles. Vol. 1998, Paper No. 98-S9-O-15. National Highway Traffic Safety Administration, 1998.

⁸⁵ See SA572-S117 and SA572-S121.
⁸⁶ Alliance of Automobile Manufacturers, Inc. (2016). Technical Considerations Concerning NHTSA's Proposal to Rework the Agency's New Car Assessment Program (NCAP). *Regulations.gov* Docket ID NHTSA-2015-0119-0313, available at: <https://www.regulations.gov/contentStreamer?documentId=NHTSA-2015-0119-0313&attachmentNumber=5&contentType=pdf>.

⁸⁷ See Figure 1 in Hagedorn, A., Murach, M., Millis, W., McFadden, J., Parent, D., (2019). Comparison of the THOR-50M IR-TRACC Measurement Device to an Alternative S-Track Measurement Device. Proceedings of the Forty-Seventh International Workshop on Human Subjects for Biomechanical Research.

⁸⁸ NHTSA is placing a separate document, "Supplemental Technical Appendices to Preamble," in the docket for this rulemaking.

⁸⁹ National Highway Traffic Safety Administration (2016). IR-TRACC Direct Replacement Sensor. Solicitation Number DTNH2216Q00014, available at <https://sam.gov/opp/d505f6119f9a31bcdfa36607ed669e6b/view>.

⁹⁰ Pfeifer, G. (2020). *U.S. Patent No. 10,713,974*. Washington, DC: U.S. Patent and Trademark Office.

⁹¹ European New Car Assessment Program (2022). Euro NCAP Supplier List, Appendices I & II, October 2022, TB 029, available at: <https://www.euroncap.com/en/for-engineers/supporting-information/technical-bulletins/https://www.euroncap.com/en/for-engineers/protocols/adult-occupant-protection/>.

⁹² This evaluation of alternate thorax and abdomen instrumentation only considered replacement of the displacement transducer component of the 3D IR-TRACC measurement system. Though it was not available at the time of purchase, a double gimbal kit to allow 3D measurement is now available from the S-Track manufacturer. ATD-Labtech GmbH (2017). 3D Adaption THOR-50th upper Thorax left 20_303. Available at: https://www.atd-labtech.com/files/atd/uploads/produkte/s-track/produkte/4%20TH-3D-Adapter-Upper-Thorax-left/data_sheet-3D-Adaption_Thor-50th_upper_Thorax_left%20Rev%2001.PDF. To evaluate whether the S-Track 3D adaption kit would result in equivalent measurement capabilities as the 3D IR-TRACC measurement system, the testing described here would be repeated, starting with the 3D static measurement assessment.

⁹³ Hagedorn, A., Murach, M., Millis, W., McFadden, J., Parent, D., (2019). Comparison of the THOR-50M IR-TRACC Measurement Device to an Alternative S-Track Measurement Device. Proceedings of the Forty-Seventh International Workshop on Human Subjects for Biomechanical Research. Available at: https://www-nrd.nhtsa.dot.gov/pdf/bio/proceedings/2019/Hagedorn_S-Track_Biomechanics%20Workshop%202019_FINAL.pdf.

(damage to the cable at the base of the S-Track). This issue is mitigated if cable routing documentation is followed or the S-Track-specific double-gimbal assembly is used.

- The S-Track performed equivalently in qualification tests. NHTSA carried out the qualification tests for the body regions expected to be sensitive to a difference in thorax and abdomen instrumentation (upper thorax, lower thorax, and abdomen) on a THOR-50M in two different configurations: a baseline configuration with IR-TRACCs in all locations, and an alternate configuration with S-Tracks in all locations. Both configurations met the qualification targets for all of the test modes specified for those body regions, which demonstrates that the difference in measured deflections between the S-Track and IR-TRACC were well within expected test-to-test variation. In addition, the deflection time-history was qualitatively similar to the IR-TRACC.

- The S-Track performed equivalently to the IR-TRACC in most respects in a series of sled tests. NHTSA conducted sled tests in several conditions with the THOR-50M in two configurations: one with the IR-TRACC in all locations, and one with the S-Track in all locations:

- The first series used a reinforced buck representative of the front half of a mid-sized passenger vehicle (including seat belt, frontal air bag, and side curtain air bag) and simulated a near-side frontal oblique (20 degrees) crash. The crash pulse was based on a frontal oblique crash test of the same vehicle. The S-Track proved to be durable and did not demonstrate the same noise artifacts as the IR-TRACC. The S-Tracks in the thorax showed similar measurements as the IR-TRACCs, particularly in the upper right thorax, the closest measurement location to the shoulder belt. There were some potential differences between the abdomen measurements, but abdominal deflection is not currently included as an injury criterion in FMVSS No. 208 and is not currently included in the rating calculation for frontal NCAP.⁹⁴

- The second series of sled tests were conducted in the Gold Standard 1 (40 km/h, 12g peak pulse, standard lap and shoulder belt) and Gold Standard 2 (30km/h, 9g peak pulse, 3kN load limited shoulder belt) test conditions, which were used both in biofidelity assessment and in the development of

⁹⁴ Additional evaluation would be desirable in cases where abdominal deflection is a critical measurement, such as a rear seat environment where submarining may be more likely to occur.

thoracic injury criteria.⁹⁵ The goal of this testing was to determine if any differences occurred between the IR-TRACC and S-Track measurement devices, and if so, whether the magnitude of these differences would affect the biofidelity and injury criteria development analyses. NHTSA is preparing a report on this second series of sled tests, which will be placed in the research docket when it is complete.

Based on this testing and analysis, NHTSA believes that the S-Track is equivalent to the IR-TRACC (with the potential exception of the abdomen deflection in a sled test environment).

Proposal

NHTSA proposes to specify both the IR-TRACC and the S-track as permissible instrumentation for the THOR-50M. A THOR-50M configured with all IR-TRACCs or all S-tracks would conform to Part 572 and NHTSA could perform compliance testing with either device installed in the THOR-50M. The dummy has not been tested in a mixed configuration, with both devices installed (*e.g.*, IR-TRACCS in the chest and S-Tracks the abdomen, or with one IR-TRACC and three S-Tracks in the chest). The overall effects of such configurations are unknown. NHTSA seeks comment on whether the final specifications should allow such configurations. The IR-TRACC is specified in the 2023 drawing package (in SA572-S117 and SA572-S121). NHTSA has not yet published engineering drawings and parts packages to specify how the S-Track is installed in the dummy, but intends to integrate such documentation into the associated technical data package components upon finalization of this proposal. NHTSA seeks comment on this proposal.

F. Shoulder

The THOR-50M shoulder was developed to allow a human-like range of motion and includes a clavicle linkage intended to better represent the human shoulder interaction with shoulder belt restraints.⁹⁶ Clavicle load cells that can be installed in the proximal and distal ends of the clavicles are commercially available, but these

⁹⁵ The Gold Standard 1 test uses a flat rigid seat, standard lap and shoulder belts, knees restrained, and right front passenger restraint geometry. The Gold Standard 2 test uses a flat rigid seat, a force-limited shoulder belt and standard lap belt, knees restrained, and right front passenger restraint geometry.

⁹⁶ Törnqvist, F.V., Holmqvist, K., Davidsson, J., Svensson, M.Y., Håland, Y., Öhrn, H., "A New THOR Shoulder Design: A Comparison with Volunteers, the Hybrid III, and THOR NT," *Traffic Injury Prevention*, 8:2, 205-215, 2007.

load cells are not currently defined in the drawing package and NHTSA has not evaluated them.

Below we discuss shoulder components for which NHTSA is proposing alternative permissible specifications (the alternate shoulder) or for which design modifications have been developed by external THOR-50M users but which NHTSA has tentatively decided not to incorporate in the drawing package (shoulder slip and coracoid process).

1. Alternate Shoulder Specification

Portions of the shoulder assembly specified in the 2018 drawing package (referred to as the SD-3 shoulder) are covered by a patent issued to Humanetics. However, for the reasons discussed in more detail in Section VIII, NHTSA has generally avoided specifying in Part 572 patented components or copyrighted designs without either securing agreement from the rights-holder for the free use of the item or to license it on reasonable terms or developing an alternative unencumbered by any rights claims. NHTSA has therefore designed, built, and tested an alternative design for a part of the shoulder assembly referred to as the shoulder pivot assembly that is not subject to any intellectual property claims. Accordingly, the proposed drawing package (the 2023 drawing package) includes specifications for the SD-3 shoulder pivot assembly as well as the alternate shoulder pivot assembly, so that either may be used. We explain this in more detail below.

SD-3 Shoulder

The SD-3 shoulder is notably different from the shoulder specified for the THOR-NT. The THOR-NT design includes a clavicle linkage attached by ball joints at the sternum and acromion, a linkage between the acromion and the scapula to which the upper arm attaches, and a linkage representing the scapula that attaches to the acromion linkage and the spine with unconstrained revolute joints. While there were some benefits of the THOR-NT design compared to existing ATDs at the time, the range of motion of the THOR-NT shoulder was found to be lacking compared to the human shoulder.⁹⁷

An improved shoulder design was independently initiated by the Chalmers University of Technology (Chalmers), in

⁹⁷ Shaw, G., Parent, D., Purtsezov, S., Lessley, D., Crandall, J., Tornvall, F., "Torso Deformation in Frontal Sled Tests: Comparison Between THOR-NT, THOR-NT with the Chalmers SD-1 Shoulder, and PMHS," *Proceedings of the International IRCOBI Conference*, 2010.

a project sponsored by Volvo and Autoliv, that sought to improve the prediction of occupant response in offset and oblique frontal crashes. Several prototype shoulder assemblies were constructed and evaluated, the most promising being labeled the Shoulder Design 1 (SD-1).⁹⁸ The SD-1 shoulder design includes a clavicle linkage with human-like geometry, connected by cardan joints to the sternum and acromion; a linkage representing the scapula that includes attachment to the upper arm; and a two-part linkage connecting the scapula to the spine which allows both upward and anterior motion of the shoulder assembly. The anterior rotation of the scapula linkage about a vertical shaft is governed by a coil spring within an assembly mounted to the spine box. Several rotation stops are installed throughout the assembly to prevent metal-to-metal contact at the extents of the range-of-motion.

After evaluation of the SD-1 in dynamic sled testing in comparison to the standard THOR-NT shoulder and to PMHS,⁹⁹ several improvements were proposed, including durability improvements to the humerus joint, decreasing the range of motion in the anterior and superior directions, and increasing the range of motion in the posterior and medial directions. The improved design, labelled as the SD-2 shoulder, was fabricated by GESAC to Chalmers' specifications, installed on a THOR-50M ATD, and evaluated in sled tests in the Gold Standard 1 and Gold Standard 2 conditions at the University of Virginia.¹⁰⁰ Several additional durability and usability concerns were raised upon post-test inspection, including deformation of the joint between the clavicle and the acromion and hard contact to the humerus joint.

Subsequently, an updated version of the SD-2 shoulder, known as the SD-3, was designed and fabricated as part of the European Union's Thoracic Injury Assessment for Improved Vehicle Safety (THORAX) project.¹⁰¹ Changes introduced in the SD-3 design included redesigned sterno-clavicular joint anthropometry, an updated shoulder cover, and improvements intended to

address the durability and usability concerns raised by the University of Virginia testing. These latter improvements consisted of replacing the clavicle U-joint with a spherical joint; replacing the humerus joint with a metric version of the HIII-50M upper arm joint; and introducing a series of washers and bushings to the bottom of the vertical shaft to enable the resistance of the assembly to be adjusted to allow a more reproducible initial position.

The SD-3 shoulder was installed on a THOR-50M ATD and sled testing was again carried out at the University of Virginia in the Gold Standard 1 and Gold Standard 2 conditions, as well as a variation of Gold Standard 1 with a force-limited belt.¹⁰² The SD-3 shoulder assembly was inspected in detail throughout this testing, and no evidence of damage was identified. The chest deflection and torso motion was similar to the SD-1 and SD-2 shoulders, while durability was improved. NHTSA also conducted an evaluation of blunt thoracic impact response of several configurations of THOR-50M ATDs and found the iteration with the SD-3 shoulder assembly installed to have the highest qualitative and quantitative biofidelity.¹⁰³ Given these findings, NHTSA modified the drawing package to include the SD-3 shoulder. The first iteration of the drawing package to include the SD-3 shoulder was published as the September 2014 version.¹⁰⁴

After the publication of the September 2014 drawing package, Humanetics filed an application for a patent describing a shoulder assembly as well as an upper arm with an integrated load cell.¹⁰⁵ Similar to the SD-3 shoulder, the design patent describes a shoulder pivot assembly which includes, among other things, a coil spring and an adjustable resistance element. After discussions between NHTSA and Humanetics, a disclaimer stating that portions of the THOR-50M drawings were covered by a

Humanetics patent was added first to the NHTSA website where the drawings were available for download, and later to the drawings for the shoulder and upper arm assemblies in the drawing package itself.

NHTSA has generally avoided specifying such parts, consistent with the legislative history of the Safety Act. (See Section VIII, Intellectual Property.) For this reason, as explained below we are also proposing, in addition to the SD-3 shoulder, an alternative shoulder pivot assembly design.

Alternate Shoulder Pivot Assembly Design

To address the potential issues with specifying only a proprietary shoulder design, NHTSA has designed, built, and tested an alternate shoulder pivot assembly that is not subject to any intellectual property claims. The alternate shoulder pivot assembly does not include any components to adjust the resistance of the assembly, and does not use a coil, clock, or watch-spring mechanism. Instead, the alternate shoulder pivot assembly design uses a molded rubber cylinder acting as a torsion bar. The top of the cylinder is attached to the shoulder support assembly and the bottom is attached to the spring housing, so rotation of the shoulder about the local Z-axis of the ATD results in torsion of the rubber cylinder. In order to adjust the resistance of the assembly, the springs must be removed and replaced.

NHTSA has evaluated the alternate shoulder in a variety of tests and tentatively concludes that its performance is similar to the SD-3 shoulder based on testing carried out to date. This testing, which included a partial qualification test series and sled tests, is briefly summarized below. A more detailed discussion of this material is available in a testing report that NHTSA is preparing, and which will be placed in the research docket when it is completed. NHTSA is also preparing another report that describes additional sled testing that was conducted; this report will be placed in the research docket when it is complete.

First, the alternate shoulder was installed in a THOR-50M without any issues regarding the form, fit, or function. Second, in a quasi-static rotation test, the alternate shoulder showed a similar moment-rotation loading slope to the SD-3 shoulder in both the forward and rearward rotation directions. Third, the SD-3 and alternate shoulder showed nearly identical longitudinal motion in all three loading directions in a quasi-static biofidelity evaluation comparing each

¹⁰² Crandall, J. (2013). ATD Thoracic Response: SD3 Shoulder Evaluation. NHTSA Biomechanics Database, Report b11470R001, available at: <https://www-nrd.nhtsa.dot.gov/database/MEDIA/GetMedia.aspx?stno=11470&index=1&database=B&type=R>.

¹⁰³ Parent, D., Craig, M., Ridella, S., McFadden, J., "Thoracic Biofidelity Assessment of the THOR Mod Kit ATD," The 23rd Enhanced Safety of Vehicles Conference, Paper No. 13-0327, 2013.

¹⁰⁴ National Highway Traffic Safety Administration (2014). THOR 50th Percentile Male Drawing Package, September 2014. available at: https://www.nhtsa.gov/DOT/NHTSA/NVSBiomechanics%20&%20Trauma/THOR%20Advanced%20Crash%20Test%20Dummy/thoradv/THOR-M_PDF_2014-09-29.pdf.

¹⁰⁵ Been, B., & Burleigh, M. (2017). U.S. Patent No. 9,799,234. Washington, DC: U.S. Patent and Trademark Office.

⁹⁸ Törnvall et al. (2007), 205–215.

⁹⁹ Shaw et al (2010).

¹⁰⁰ Crandall, J. (2013). ATD Thoracic Response: Effect of Shoulder Configuration on Thoracic Deflection. NHTSA Biomechanics Database, Report b11017R001, available at: <https://www-nrd.nhtsa.dot.gov/database/MEDIA/GetMedia.aspx?stno=11017&index=1&database=B&type=R>.

¹⁰¹ Lemmen, P., Been, B., Carroll, J., Hynd, D., Davidsson, J., Song, E., and Lecuyer, E. (2012). Development of an advanced frontal dummy thorax demonstrator. Proceedings of the 2012 IRCOBI Conference, Paper No. IRC-12-87, September 2012.

shoulder's range of motion to that of human volunteers; the responses of both were generally similar to the human volunteer response corridors. Fourth, the qualification tests most likely to be affected by shoulder response (upper thorax and chest) were carried out; the THOR-50M with the alternate shoulder met all qualification specifications for the upper thorax, and the force-deflection characteristic of the chest was nearly identical to that of a THOR-50M with the SD-3 shoulder. Finally, sled tests conducted in both a full frontal and a far-side oblique condition did not reveal any durability or usability issues, and the response of the THOR-50M with the alternate shoulder was within the test-to-test variation of the THOR-50M with the SD-3 shoulder.

NHTSA is therefore proposing the alternative shoulder as an acceptable optional subassembly. The shoulder assemblies are specified on drawings 472-3810 (left) and 472-3840 (right). Each shoulder assembly drawing specifies that either the SD-3 shoulder pivot assembly or the alternate shoulder pivot assembly may be used. The proposed specifications for the SD-3 shoulder pivot assembly are provided in drawings 472-3811 and 472-3841, and the proposed specifications for the alternate shoulder pivot assembly are provided in drawings 472-6810-1 and 472-6810-2. The drawing package currently indicates that the selection of which shoulder pivot assembly to use is made separately for the left and right shoulder assemblies, so that the dummy could be fitted with the SD-3 shoulder pivot assembly on one side, and the alternate shoulder pivot assembly on the other side. The dummy has not been tested in such a mixed configuration, and the overall effects of such configurations are unknown. NHTSA seeks comment on whether the final specifications should allow such mixed configurations.

NHTSA seeks comment on whether the final drawing package should include the SD3 shoulder, the alternate shoulder, or both. NHTSA also seeks comment from THOR-50M users who have evaluated the proposed alternate shoulder design, or other alternate shoulder designs, and have data related to equivalence with respect to durability, repeatability and reproducibility, and response in qualification, biofidelity, injury and vehicle crash test conditions.

2. Shoulder Slip

NHTSA is aware that some researchers and regulatory authorities have identified what they view as a possible design flaw in the shoulder—

that the shoulder belt may slip towards the neck in a crash—and have developed potential modifications to the shoulder design to prevent this from happening.

This concern was first raised in a 2018 conference paper describing research conducted by Transport Canada. Transport Canada conducted a series of vehicle crash tests with the THOR-50M in the driver seat in two conditions: 40% offset and full frontal rigid barrier.¹⁰⁶ It was reported that the upper portion of the shoulder belt could translate towards the neck and become entrapped in the gap between the neck and the shoulder. This occurred in 33 of the 45 offset tests and in 2 of the 13 full frontal rigid barrier tests. Compared to tests without shoulder belt slip, tests with shoulder belt slip showed higher measurements for lower neck shear (X-axis and Y-axis force), higher chest deflections in the upper left and lower right quadrants, and lower clavicle axial forces.

Following that research, a 2019 Humanetics study identified and evaluated three prototype alternative modifications to the shoulder specified in the 2018 drawing package to prevent the shoulder belt from entering the gap between the neck and the shoulder.¹⁰⁷ The study concluded that all three prototype modifications prevented belt entrapment and identified the preferred design alternative (referred to as a profiled split design). While the shoulder specified by NHTSA uses the same material for the entire shoulder pad, the profiled split design replaces the material closest to the neck with a higher-stiffness plastic material. This is intended to prevent the collar (the portion of the shoulder pad closest to the neck) from deforming and allowing the shoulder belt to slip towards the neck.

In addition, in recent discussions with NHTSA, Euro NCAP has noted that several instances of shoulder belt slippage were observed in Euro NCAP testing as well as research tests with the mobile progressive deformable barrier. Euro NCAP reported that it was evaluating two potential shoulder design modifications, and expected these to be presented for approval in 2023.

While NHTSA has witnessed the shoulder belt moving towards the neck

in vehicle crash tests, this phenomenon does not appear to influence dummy measurements related to injury criteria. NHTSA seeks comment on the desirability of and specifications for a modification to prevent belt slippage, including data on testing with the proposed shoulder design showing that it is leading to belt slippage that has a meaningful effect on test results. NHTSA also requests comment from THOR-50M users who have evaluated the split shoulder pad (or any available alternatives) and have data to support equivalence of durability, repeatability and reproducibility, and response in qualification, biofidelity, injury criteria, and vehicle crash test conditions.

G. Hands

The THOR-50M specified in the 2023 drawing package includes the same hand design as the HIII-50M. The drawing defining the hand assembly of the THOR-50M¹⁰⁸ includes material formulation (Solid Vinyl, Formulation Portland Plastics, PM-7003) along with two two-dimensional images and one three-dimensional image of the hand. Additionally, the three-dimensional geometry of the hand assembly is included in the computer-aided design (CAD) files available through the NHTSA website in both Autodesk Inventor and generic STEP formats. However, the vinyl call-out does not sufficiently specify the hardness or the stiffness of the material formulation and may be insufficient to define the part. NHTSA therefore seeks comment on whether there is a need for a material test (e.g., hardness measurement or a quasi-static compression test of a coupon of the material) or performance test (e.g., quasi-static or dynamic impact to the as-fabricated hand) to further define the hand assembly of the THOR-50M, and if so, what the test might be.

H. Spine

The spine of the THOR-50M ATD is primarily constructed of steel. There are two flexible elements (one in the thoracic spine and one in the lumbar spine) that are intended to allow human-like spinal kinematics in both frontal and oblique loading conditions.¹⁰⁹ Between the two flexible elements is a posture adjustment joint known as the lumbar spine pitch change mechanism, which allows the posture of the THOR-50M to be adjusted into various seating configurations in three-

¹⁰⁶ Tylko, S., Tang, K., Giguere, F., Bussieres, A. (2018). Effects of Shoulder-belt Slip on the Kinetics and Kinematics of THOR. Proceedings of the 2018 IRCOB Conference.

¹⁰⁷ Wang, Z.J., Fu, S., McInnis, J., Arthur, J. (2019). Evaluation of Novel Designs to Address the Shoulder-belt Entrapment for THOR-50M ATD. Proceedings of the 2019 IRCOB Conference.

¹⁰⁸ Drawing 472-6900-1/2.

¹⁰⁹ Haffner, M., Rangarajan, N., Artis, M., Beach, D., Eppinger, R., Shams, T. (2001). Foundations and Elements of the NHTSA THOR Alpha ATD Design. The 17th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 458.

degree increments, including, but not limited to, four designated positions (erect, neutral, slouched, and super slouched).¹¹⁰ The spine is instrumented with a five-axis thoracic spine load cell mounted below the lumbar spine pitch change mechanism and above the lumbar spine flex joint (a flexible joint that allows the dummy to go into flexion/extension in the lumbar region). Triaxial accelerometers can be installed in the nominal locations of the first, sixth, and twelfth thoracic vertebra.

The proposed spine design differs from the THOR-50M used by Euro NCAP. Whereas the 2023 drawing package specifies a lumbar spine pitch change mechanism, TB026 specifies a four-position lumbar spine box or an “alternative spine box” if “data has been provided to show equivalence between the NHTSA spine assembly and modified spine assembly.”¹¹¹ Humanetics holds a patent on the four-position spine. The four-position lumbar spine is not specified further, but it does differ from the spine specified by the NHTSA drawings. The spine pitch change mechanism specified in the 2023 drawing package allows the spine to be set at a multitude of flexion or extension settings, not just four. NHTSA understands that the Euro NCAP design is intended to accommodate the in-dummy installation of some DAS brands by providing a mounting surface for data loggers. THOR-50M units built for Euro NCAP are configured with in-dummy DAS systems have the four-position spine.

NHTSA has tentatively decided not to specify a lumbar spine pitch change mechanism limited to four positions for a few reasons. First, NHTSA has not inspected, nor has it performed any testing with, the four-position spine. Second, NHTSA generally avoids specifying patented components in Part 572 (see Section VIII, Intellectual Property). Third, the proposed spine specifications provide more adjustability than the four-position spine so the dummy may be used in a wider range of applications. NHTSA seeks comment on user experience with the four-position spine, including any data on equivalence with the THOR-50M as specified in the 2023 drawing package or biofidelity.

It is also NHTSA’s understanding that members of Working Group 5 have observed variations in the ATD responses in the upper thorax qualification tests that have led to difficulties in meeting the Euro NCAP qualification specifications. Some

manufacturers have suggested that this variation in response is due to variation in the spine flex joint (specifically, the vertical displacement (Z-axis) of the ribs is too high). One potential cause that has been identified (by Porsche in November 2019) is that the hardness of the material comprising the spine flex joint was lower than the specification called for.

NHTSA’s qualification testing did not reveal any issues with meeting the upper thorax qualification specifications (See Section V.D). In any case, in light of the potential concerns raised within Working Group 5 of possible excessive variation in the performance of the spine flex joint, potentially traceable to out-of-specification materials, NHTSA conducted a limited modeling exercise using the THOR-50M Finite Element (FE) model to investigate this. This analysis suggested that while variation in the lumbar and thoracic spine flex joints does influence the thoracic response in both qualification and sled test conditions, this variation is smaller than the expected test-to-test and ATD-to-ATD variation; specifically, a decrease in stiffness of the spine flex joints can influence the upper thorax qualification response, but by a much smaller magnitude than the width of the qualification specifications and test-to-test and ATD-to-ATD variations. For more information on this issue and NHTSA’s FE modelling, please see Appendix B.

Nonetheless, a research effort is currently underway to assess the influence of the lumbar and thoracic spine flex joints in physical qualification tests (which would provide additional validation data to the computational analysis) and develop isolated dynamic tests of the lumbar and thoracic spine flex joints. Based on these results, NHTSA could potentially consider adding such a test(s) in the drawing package, qualification procedures, or laboratory test procedures. NHTSA requests comment from THOR-50M ATD users who have data to demonstrate variation in THOR-50M response that is believed to result from spine flex joint variation, specifically when the parts evaluated met the specifications of the THOR-50M drawing package. Additionally, NHTSA requests comment on the need for a thoracic spine and/or lumbar spine flex joint specification beyond the geometry and material properties defined in the drawing package.

I. Abdomen

The abdomen of the THOR-50M consists of two components, the upper abdomen and the lower abdomen. The

lower abdomen is the region between the lower thoracic rib cage and the pelvis. The upper abdomen is the region on the dummy that represents the lower thoracic cavity, which fills the volume that exists between the lowest three ribs, above the lower abdomen and in front of the spine. The upper and lower abdomen components of THOR-50M are represented by structural fabric bags containing foam inserts which define the compression stiffness. Both abdomen inserts are anchored posteriorly to the spine, while the upper abdomen insert is additionally anchored to the lower rib cage. When the lumbar spine pitch change joint is set to the “slouched” position, the abdomen inserts are in contact with one another; when in the “erect” and “neutral” positions, the gap between the abdominal inserts is filled with the lower abdomen neutral/erect position foam. This gap is also spanned by two steel stiffeners on each side that are installed into the torso jacket. The bottom surface of the lower abdomen insert is coincident with the pelvis.

J. Pelvis

The THOR-50M pelvis is designed to represent human pelvis bone structure to better represent lap belt interaction,^{112 113} and the pelvis flesh is designed to represent uncompressed geometry to allow human-like interaction of the pelvis flesh with the vehicle seat.¹¹⁴ The pelvis assembly is constructed of a steel and aluminum structure representing bone surrounded by a molded foam-filled vinyl covering representing flesh. The flesh is not physically connected to the pelvis bone but is held in place due to the tight fit of protrusions of the pelvis bone into recesses in the pelvis flesh, as well as circular bosses in the pelvis flesh into recesses in the pelvis bone. The pelvis flesh includes a portion of the upper thigh flesh, the interior surface of which includes gaps around the femur bone to allow articulation of the leg about the hip joint.

The THOR-50M pelvis flesh is a molded component, with a vinyl outer

¹¹² Reynolds, H., Snow, C., Young, J., “Spatial Geometry of the Human Pelvis,” U.S. Department of Transportation, Technical Report No. FAA-AM-82-9, 1982.

¹¹³ Haffner, M., Rangarajan, N., Artis, M., Beach, D., Eppinger, R., Shams, T., “Foundations and Elements of the NHTSA THOR Alpha ATD Design,” The 17th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 458, 2001.

¹¹⁴ Shams, T., Rangarajan, N., McDonald, J., Wang, Y., Platten, G., Spade, C., Pope, P., Haffner, M., “Development of THOR NT: Enhancement of THOR Alpha—the NHTSA Advanced Frontal Dummy,” The 19th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 05-0455, 2005.

¹¹⁰ See Fig. 5-32 in the PADI.

¹¹¹ § 1.4.3.

layer filled with expandable polyurethane foam. The two-dimensional drawing includes top, side, front, and isometric views of the molded pelvis flesh, while its three-dimensional geometry is included in the CAD files available through the NHTSA website in both Autodesk Inventor and generic STEP formats. The drawing package specifies part weight and foam density¹¹⁵ but not a material response or performance requirement for the pelvis flesh.

NHTSA is considering adding a performance specification for the pelvis flesh similar to that defined in the HIII-50M PADI. Such a performance specification would dictate the amount of allowable compression of the pelvis flesh under a defined load. A similar test was conducted on the pelvis flesh during the THOR Alpha design development.¹¹⁶ One such possible requirement would be the compression at a force of 500 N. Alternatively, Porsche has suggested a dynamic impact test using an impactor similar to that used in the upper thorax qualification test to impact the bottom of the pelvis flesh at a velocity of 2 m/s. NHTSA seeks comment on the need and specifications for a pelvis compression test, including whether it should be a qualification requirement, a drawing specification, or otherwise.

The pelvis is instrumented with bi-lateral triaxial load cells attached to the acetabulum (in order to measure the reaction force between the femur and the pelvis) and a triaxial accelerometer array at its center of gravity. The pelvis is also instrumented with bi-lateral anterior-superior iliac spine (ASIS) load cells that measure contact force in a nominally longitudinal axis and moment about a nominally lateral axis. The ASIS load cell is primarily used to measure the force transferred to the pelvis through the lap belt, in which case the moments can be used to determine the vertical level or center of pressure of the lap belt force.

K. Upper Leg

The upper leg assembly is constructed of steel and aluminum and includes a rubber compressive element at the middle of the femur shaft. This compressive element consists of a steel plunger that can translate axially along the femur shaft through a guide system. When the femur is loaded in axial compression (e.g., pushing the knee towards the pelvis parallel to the

femur), the motion of the plunger is resisted by a rubber element, which allows a human-like compression response.¹¹⁷ At the proximal end, the femur is connected to the pelvis through a ball joint in a socket attached to the acetabulum load cell. At the distal end, there is a six-axis load cell attaching the femur to the knee assembly.

L. Knee

The THOR-50M knee is similar in construction to that of the HIII-50M, with a few differences. The primary structure of the knee cap is fabricated from aluminum, attached proximally to the femur load cell. Inside of the kneecap assembly, a slider mechanism is installed to allow translational motion of the tibia with respect to the knee. The knee slider includes a stop assembly to prevent metal-to-metal contact and to define the force-deflection characteristic of the tibia translation. Attached to the slider is a string potentiometer to measure the magnitude of tibia translation relative to the knee. The sides of the kneecap are enclosed by urethane covers to protect the slider mechanism, and the knee assembly is wrapped in a foam-filled vinyl cover representing knee flesh.

The design of the knee slider modifies the HIII-50M design by changing the geometry and material properties of the molded slider assemblies (472-5320 and 472-5330) and stop assemblies (472-5358).¹¹⁸ This change was made because at levels of knee displacement below the 10.2-millimeter (mm) biofidelity response requirement, the HIII-50M has been found to be stiffer than PMHS response corridors. Thus, during the THOR-50M Mod Kit project, biomechanical response requirements were specified with an additional measurement point at 5 mm of knee displacement with a force between 100 and 500 N. The Mod Kit also relegated the measurement point at 10.2 mm of deflection to a secondary requirement, as it was shown to be at the high end of the underlying PMHS corridors. While the 5 mm and 17.8 mm response requirements were met by the revised THOR-50M knee slider,¹¹⁹ the force-deflection response was below the human response corridor between 8 mm and 15 mm of deflection, but above the corridor after 18 mm of deflection.¹²⁰ As such, when the biofidelity was

evaluated using BioRank, the external biofidelity score of 2.282 indicated that the THOR-50M response was more than two standard deviations from the PMHS mean response. This BioRank score was lower than the corresponding HIII-50M score (1.070). This should be taken into consideration when using the THOR-50M to evaluate the risk of ligamentous knee injury.

M. Lower Leg

The mechanical design of the THOR-50M lower extremity includes a compressive rubber section in the tibia shaft, similar to the compliant femur section, which provides more biofidelic force transmission from the heel to the knee. The spring damper Achilles tendon system aids in producing biofidelic ankle motion and torque characteristics. The ankle design allows rotation about three axes, representing inversion/eversion, dorsi/plantar-flexion, and axial rotation, and includes molded rubber elements to define the moment/rotation response and limit metal-to-metal contact at the extents of the range of motion. Different from existing ATDs, the THOR-50M includes a molded shoe design which integrates the foot and shoe into a single part. This feature, added in the 2016 update to the THOR-50M drawing package,¹²¹ is intended to reduce potential variability in the response of commercially available shoes.

Euro NCAP TB026 deviates from the proposed drawing package in that it specifies the HIII-50M lower legs, including the military specification¹²² shoes, knee slider sensor, and roller ball-bearing knees. We believe the THOR-50M specifications are preferable, for the reasons given above (e.g., biofidelity).

Each lower leg can be instrumented with five-channel load cells in the upper and lower tibia, a uniaxial load cell to measure the Achilles cable force, and three rotary potentiometers to measure the rotation of the individual ankle joints. Two uniaxial accelerometers can be mounted to the tibia and a tri-pack accelerometer assembly can be mounted to each foot plate.

N. Data Acquisition System

Testing with THOR-50M requires (as does testing with any dummy) a data

¹¹⁷ Ridella, S., Parent, D., "Modifications to Improve the Durability, Usability, and Biofidelity of the THOR-NT Dummy." The 22nd International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 11-0312, 2011. See Figure 17.

¹¹⁸ *Id.* at Figure 16.

¹¹⁹ *Id.*

¹²⁰ See Biofidelity Report, p. 254 (Fig. 45).

¹²¹ National Highway Traffic Safety Administration (2016). Parts List and Drawings THOR-50M Advanced Frontal Crash Test Dummy THOR-50M Male August 2016. Docket ID NHTSA-2015-0119-0376.

¹²² Specification is not stated in Euro NCAP TB026, but believed to be MIL-S-13192P as specified in 49 CFR 571.208 S8.1.8.2.

¹¹⁵ Drawing 472-4100.

¹¹⁶ White Jr, R.P., Rangarajan, N., Haffner, M., "Development of the THOR Advanced Frontal Crash Test Dummy", 34th Annual SAFE Symposium, Conference paper, 1996.

acquisition system (DAS). The data acquisition system performs signal conditioning, triggering, and data collection to store measurements from instrumentation installed in the dummy during a test into nonvolatile memory. As it relates to ATDs, there are effectively two types of DAS: external and internal (or in-dummy). As we explain below, while the 2018 drawing package does not specify a DAS (because it assumes the use of an external DAS), NHTSA is proposing to specify an optional in-dummy DAS.¹²³

An external DAS is, as the name indicates, external to the dummy. The instrumentation in the dummy is connected to the external DAS via wires, sometimes referred to as an umbilical cable. The 2018 drawing package does not explicitly specify a DAS or related equipment, but the drawings assume an external DAS: they assume that the instrumentation wires are long enough to be bundled into an umbilical cable and connected to a DAS located in the lab or mounted to the vehicle in which the ATD is seated.

An internal DAS is installed within the dummy itself. An internal DAS has some advantages to an external DAS. The primary advantage is related to the mass properties of the dummy. With an internal DAS system, there are no external cables that may possibly affect body segment masses; segment masses are always the same no matter how the dummy is used. While upfront cost is higher, an internal DAS would reduce per-test costs, eliminate the need for interface cables to lab-specific DAS systems (which have been a frequent source of instrumentation failures in research testing), and reduce the adjustments needed to arrive at the target test vehicle weight. Feedback from industry¹²⁴ as well as Euro NCAP indicates that users prefer an in-dummy DAS for its many usability advantages. Euro NCAP TB026 requires an in-dummy DAS.¹²⁵ While Euro NCAP TB029 currently does not specify an approved in-dummy DAS,¹²⁶ earlier

versions of TB029 did specify a few different approved in-dummy DAS systems.¹²⁷

In light of these potential advantages and user preferences, NHTSA sponsored development and testing of an in-dummy DAS. NHTSA published a request for solicitation for an in-dummy DAS.¹²⁸ This was before Euro NCAP began testing with the THOR-50M. The solicitation favored a minimal redesign of existing THOR-50M parts, in order to facilitate interchangeability of parts between THOR-50Ms with and without in-dummy DASs. NHTSA contracted Diversified Technical Systems (DTS) to implement its SLICE6 data acquisition system in a NHTSA-owned THOR-50M. This included delivery of DAS components, replacement instrumentation compatible with the DAS, and replacement ATD parts to allow attachment of DAS components and preservation of inertial properties. The resulting implementation distributes a series of small 6-channel data acquisition modules throughout the ATD, mounted directly on load cells or sensors where possible, or close to the sensor with short cables to the sensor. The DAS modules are chain-networked with four wiring harnesses which connect to the SLICE6 Distributor, with a single ATD exit cable connecting the DAS to the full test system.

NHTSA evaluated the overall performance and equivalence of the THOR-50M with the in-dummy SLICE6 DAS in a full suite of qualification testing and a variety of sled and vehicle crash testing. This research and analysis is described briefly below. The vehicle crash testing is described in more detail in the cited report. NHTSA is preparing a report on the installation, qualification testing, and sled testing of the SLICE6 in-dummy DAS, which will be placed in the research docket when it is complete. Additional information on the durability of the THOR-50M with the in-dummy DAS system is included in Section VII.B, Durability and Maintenance.

- It was possible to install the SLICE6 into the dummy with negligible changes

www.euroncap.com/en/for-engineers/supporting-information/technical-bulletins/.

¹²⁷ European New Car Assessment Programme (2022). Euro NCAP Supplier List, Version 3.1, April 2021, TB 029, available at: <https://www.euroncap.com/en/for-engineers/supporting-information/technical-bulletins/>. The DTS TDAS G5, SLICE Nano, and SLICE6; the Kistler DTI, microDAU, and NXT32; and the Messring M=BUS.

¹²⁸ National Highway Traffic Safety Administration (2017). Implement and Install THOR 50M In Dummy Data Acquisition System. Solicitation Number DTNH2217Q00033, available at: <https://sam.gov/opp/068c7821de797ebe7f9e78a0f2b68dc4/view>.

to the mass, moment of inertia, and center of gravity of the ATD and its individual body segments. This did require modifications to several THOR-50M parts (e.g., the lower thoracic spine assembly) in order to allow attachment of the DAS hardware to the rigid components of the ATD.

- NHTSA has been able to fully qualify THOR-50M ATDs with the in-dummy DAS installed. Since the SLICE system has been installed, we have used the dummy in many tests and have qualified it with no issues. The THOR-50M with the in-dummy DAS was tested in simplified sled tests. Sled tests were conducted in the Gold Standard 1 (40 km/h, 12g peak pulse, standard lap and shoulder belt) and Gold Standard 2 (30km/h, 9g peak pulse, 3kN load limited shoulder belt) test conditions, which were used both in biofidelity assessment and in the development of thoracic injury criteria. The goal of this testing was to determine if any differences occurred between the external and internal DAS configurations, and if so, whether the magnitude of these differences would affect the biofidelity and injury criteria development analyses.

- NHTSA also tested the THOR-50M with an in-dummy DAS in a series of vehicle crash tests in the OMDB test condition with three different deformable barrier faces. While some of the OMDB tests appeared to show differences between the in-dummy DAS and umbilical configurations, it was not clear whether this was due to variation in the dummy response or variation in dummy positioning, vehicle response, and/or restraint system response.¹²⁹

Importantly, this testing did not reveal any potential durability or usability issues associated with the in-dummy DAS, with one possible exception: The temperature inside the thoracic cavity of the ATD can increase beyond the ambient temperature typically prescribed for regulatory and consumer information crash tests.¹³⁰ In a more recent set of vehicle crash tests, NHTSA closely monitored the rib temperature of the THOR-50M with the

¹²⁹ Saunders, J., Parent, D. (2023). Update on NHTSA's OMDB's half barrier analysis. Proceedings of the 27th Enhanced Safety of Vehicle Conference, Yokohama, Japan.

¹³⁰ The OVSC Laboratory Test Procedures for FMVSS No. 208 specify an ambient temperature measured within 36 inches of the ATD to be between 69 and 72 degrees Fahrenheit. National Highway Traffic Safety Administration (2008). Laboratory Test Procedure for FMVSS 208, Occupant Crash Protection, TP208-14, available at: https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/tp-208-14_tag.pdf.

¹²³ We note that the 2023 drawing package itself does not contain specifications for an in-dummy DAS. Instead, the proposed in-dummy DAS specifications are set out in an addendum that is being docketed along with the 2023 drawing package.

¹²⁴ Alliance of Automobile Manufacturers, Inc. (2016). Technical Considerations Concerning NHTSA's Proposal to Rework the Agency's New Car Assessment Program (NCAP). *Regulations.gov* Docket ID NHTSA-2015-0119-0313, available at: <https://www.regulations.gov/contentStreamer?documentId=NHTSA-2015-0119-0313&attachmentNumber=5&contentType=pdf>.

¹²⁵ TB026 § 1.2.

¹²⁶ European New Car Assessment Programme (2022). Euro NCAP Supplier List, Version 4.0, October 2022, TB 029, available at: <https://www.euroncap.com/en/for-engineers/supporting-information/technical-bulletins/>.

in-dummy DAS.¹³¹ By routinely limiting the “ON” time of the DAS, NHTSA has been able to maintain the temperature range. Additionally, NHTSA has used a portable fume extractor device to aid in maintaining the temperature of the WorldSID–50M side impact dummy, which also has internal DAS system.¹³² This device may also be employed in tests with the THOR–50M.

Based on this testing, NHTSA has tentatively concluded that the THOR–50M with the in-dummy DAS is equivalent to one with the external DAS. NHTSA is therefore proposing an internal DAS as permitted optional instrumentation that it could use in its testing. This necessitates changes to the dummy to accommodate the DAS while ensuring that there are no changes to the mass, moment of inertia, and center of gravity of the ATD and its individual body segments. These changes may differ from the Euro NCAP approach specified in TB026, which permits the four-position spine box (discussed in Section III.H above) to accommodate the installation of some DAS brands by providing a mounting surface for data loggers. Euro NCAP does not provide part-by-part engineering drawings of the various DAS packages, which is necessary for THOR–50M to be sufficiently objective.

NHTSA has therefore provided, in an addendum to the 2023 drawing package, further specifications for the dummy to accommodate an internal DAS. It is anticipated that, upon finalization of this proposal, the in-dummy DAS drawings will be fully integrated within the relevant technical data package components. These specifications consist of descriptions of the instrumentation and new drawings for the dummy parts that require modifications to accommodate the DAS. The changes are specified such that the

dummy with the in-dummy DAS will have the same inertial properties as the dummy using the external DAS. The drawings show DAS mass blanks in lieu of the actual DAS components (battery, data logger, etc.) with the exterior dimensions of the blank matching those of the corresponding SLICE6 component.

If an in-dummy DAS component is not installed (for example, if lower leg instrumentation is not needed for a given test mode), the blank would be filled with a material of a specified density. The material of the blank is not specified (although a reference specification is provided) but would be selected to provide an appropriate density and may also have internal flashing holes needed to attain the desired mass, which is chosen to match the mass of the actual DAS component. It is anticipated that, upon finalization of this proposal, the PADI will show two sets of installation steps: one with the “blank” component, and one with the actual DAS parts. (This two-set convention is also followed with load cells and their structural replacements). The proposed specifications are based on, but not necessarily limited to, the SLICE6 (the SLICE6 is not explicitly specified or called-out by name), so that another system fitting within the defined specifications could also be utilized.¹³⁴

NHTSA seeks comment from users who have experience with both umbilical and in-dummy DAS configurations of the THOR–50M, as to whether they have seen any quantifiable differences between the two. NHTSA also seeks comment on whether any additional changes should be made to the proposed drawings specifying the in-dummy DAS to make it more amenable to additional DAS systems that are already in the field.

IV. Biofidelity

Biofidelity is a measure of how well the dummy replicates a human, and includes anthropometry, mass properties, range of motion, and impact response. The impact biofidelity is evaluated by comparing the response of the dummy to the response of a post-mortem human surrogate (PMHS or cadaver) or human volunteer in a variety of different test conditions (also referred to as test modes). Some of these

tests focus on individual dummy components (head, neck, chest, abdomen, upper leg, knee, lower leg) and some evaluate the entire dummy as a complete assembly.

To evaluate the biofidelity of THOR–50M, NHTSA selected test conditions based on relevance to frontal and frontal oblique crash test applications and the availability of data. For example, a neck frontal flexion test was conducted by attaching the base of the THOR–50M neck to a sled and applying a certain acceleration pulse. This was then compared to the response measured on human volunteers who were subjected to a similar pulse. Specifically, the impact biofidelity of the THOR–50M was assessed in twenty-one test conditions. The test conditions are summarized in Table 6. Each test produces a series of data points (*e.g.*, force vs. time).

The test conditions have been developed over the years by various researchers to evaluate biofidelity and have been published in peer-reviewed journals. The PMHS and human volunteer response data generally comes from this published research. The THOR–50M response data comes from testing that NHTSA has been conducting on the THOR–50M throughout its development, all of which is available in NHTSA’s Biomechanics Test Database.¹³⁵ NHTSA also compared THOR–50M’s biofidelity to that of the HIII–50M; many of the tests conducted with THOR–50M were paired with the same test conducted on the HIII–50M. In our testing we attempted to match the test conditions as closely as possible to the test conditions in the original PMHS or volunteer tests.¹³⁶

¹³⁵ Available at <https://www.nhtsa.gov/research-data/research-testing-databases#biomechanics>.

¹³⁶ Overall, while some assumptions were necessary in the reproduction of the PMHS or volunteer test conditions, we believe that these assumptions should not affect the overall biofidelity assessment of the THOR–50M. For instance, NHTSA simplified some of the original tests in order to facilitate ease of testing when we expected the simplification to have a negligible influence on the result, such as evaluating neck flexion using only the ATD’s head and neck, and not the entire dummy. These assumptions and simplifications, as well as any limitations to our analyses, are discussed in detail in the docketed biofidelity report. Parent, D., Craig, M., Moorhouse, K. 2017. Biofidelity Evaluation of the THOR and Hybrid III 50th Percentile Male Frontal Impact Anthropomorphic Test Devices. Stapp Car Crash Journal, 61, 227–276, available at: <https://www.regulations.gov/document/NHTSA-2019-0106-0004>.

¹³¹ Saunders, J., Parent, D., Martin, P. (2023). THOR–50M fitness assessment in FMVSS No. 208 unbelted crash tests. Proceedings of the 27th Enhanced Safety of Vehicle Conference, Yokohama, Japan.

¹³² Tatem, W., Loudon, A. (2023). WorldSID–50M Fitness Assessment in FMVSS No. 214 Moving Deformable Barrier and Oblique Pole Crash Tests. Proceedings of the 27th Enhanced Safety of Vehicle Conference, Yokohama, Japan.

¹³³ This device is used to dissipate heat from the dummy in the pre-test setup (for example, while seating and positioning the dummy). Typically, a tube is inserted into the dummy jacket and in conjunction with the fan is used to vent heat from the dummy to maintain an in-spec internal temperature. The apparatus is detached from the dummy immediately prior to the vehicle or sled test. Use of such a fan may be specified in the OVSC laboratory test procedure.

¹³⁴ While we are aware of in-dummy DASs produced by other manufacturers, we have not evaluated whether these systems would be compatible with the in-dummy DAS addendum to the 2023 drawing package.

TABLE 6—BIOFIDELITY CONDITIONS CONSIDERED IN THE DESIGN OF THE HIII FRONTAL DUMMIES AND THOR–50M ATDS

Body region	Test condition	Subpart E, O, W	THOR–50M
Head	Isolated Head Drop	•	•
	Whole-body Head Impact		•
	Face Rigid Bar		•
	Face Rigid Disk		•
Neck	Neck Flexion, Pendulum	•	
	Neck Extension, Pendulum	•	
	Neck Frontal Flexion, Sled		•
	Neck Lateral Flexion, Sled		•
	Neck Torsion		•
Thorax	Sternal Impact, 6.7 m/s	•	
	Sternal Impact, 4.3 m/s		•
	Lower Ribcage Oblique		•
Abdomen	Upper Abdomen Steering Rim		•
	Lower Abdomen Rigid Bar		•
	Abdomen Belt Loading		•
KTH	Femur Compression	•	•
	Knee Shear	•	•
Lower Extremity	Dynamic Heel Impact		•
	Tibia Axial Compression		•
	Dynamic Dorsiflexion		•
Whole-body	Gold Standard 1		•
	Gold Standard 2		•
	Gold Standard 3		•
	Far Side Oblique		•

The test conditions used to evaluate the THOR–50M represent an accumulation of biomechanics research. All conditions are accompanied by a well-specified, objective test procedure and a well-founded set of human response targets. The set of test conditions has grown substantially over the span of Part 572 rule makings. For example, in NHTSA’s original 1998 proposal for the Subpart O HIII–5F dummy,¹³⁷ only six biofidelity conditions were assessed.¹³⁸ Since then, the list has grown substantially; new conditions have been developed for all body regions, and whole-body sled test conditions have been developed.¹³⁹

NHTSA quantified how closely the response of the THOR–50M matched the response of the PMHS or human volunteers using the Biofidelity Ranking

system (BioRank).¹⁴⁰ BioRank has been applied in other instances cited in the literature¹⁴¹ and in other NHTSA Part 572 rulemakings.¹⁴² This methodology statistically compares the dummy response to the average PMHS/volunteer response (typically a time-series but sometimes a point estimate). A BioRank value of 0.0 indicates an ATD response identical to the average PMHS/volunteer response; a value of 1.0 indicates an ATD response that is on average one standard deviation¹⁴³ away from the average PMHS/volunteer response; a value of 2.0 indicates an ATD that is on average two standard deviations away from the average PMHS/volunteer response; and so on. Therefore, the lower the BioRank value, the better the biofidelity. We computed BioRank

scores for both the THOR–50M and the HIII–50M.

For each body region, we calculated two BioRank scores: one for external biofidelity (the extent to which the ATD represents a human surrogate to the vehicle or restraint system); and one for internal biofidelity (the ability of the ATD to represent the human responses that relate to prediction of injury). External biofidelity measures are generally those recorded at the test fixture level, such as pendulum force or belt force; internal biofidelity measures are generally those recorded by the internal instrumentation of the ATD or test equipment such as motion tracking that records subject excursion.

NHTSA considered two other methods of quantifying biofidelity. One is the International Standards Organization (ISO) 9790 Biofidelity Classification System. ISO 9790 defines the analysis process, response corridors, and weighting factors for the quantitative assessment of biofidelity of side impact ATDs. Because the ISO 9790 response corridors and weighting factors are specific to side-impact ATDs, it could not be directly applied to a frontal impact ATD such as the THOR–50M, and we are not aware of a corollary ISO standard for assessment of frontal impact ATD biofidelity. While a method similar to that described in ISO 9790 could be developed to assess frontal impact ATD biofidelity, we believe such a method may introduce subjective bias because it contains many subjective features, including weighting

¹³⁷ 63 FR 46981.

¹³⁸ Mertz, H.J., Irwin, A.L., Melvin, J.W., Stanaker, R.L., & Beebe, M. (1989). Size, weight and biomechanical impact response requirements for adult size small female and large male dummies (No. 890756). SAE Technical Paper.

¹³⁹ See National Highway Traffic Safety Administration, “Biomechanical Response Requirements of the THOR NHTSA Advanced Frontal Dummy, Revision 2005.1,” Report No: GESAC–05–03, U.S. Department of Transportation, Washington, DC, March 2005 (available at http://www.nhtsa.gov/DOT/NHTSA/NVS/Biomechanics%20&%20Trauma/THOR-NT%20Advanced%20Crash%20Test%20Dummy/thorbio05_1.pdf) and Ridella, S., Parent, D., “Modifications to Improve the Durability, Usability, and Biofidelity of the THOR–NT Dummy,” The 22nd International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 11–0312, 2011.

¹⁴⁰ Rhule, H., Maltese, M., Donnelly, B., Eppinger, R., Brunner, J., Bolte, J. (2002) Development of a New Biofidelity Ranking System for Anthropomorphic Test Devices. *Stapp Car Crash Journal* 46: 477–512.

¹⁴¹ Rhule, H., Moorhouse, K., Donnelly, B., Stricklin, J. (2009) Comparison of WorldSID and ES–2RE Biofidelity Using Updated Biofidelity Ranking System. 21st ESV Conference, Paper No.09–0563.

¹⁴² The analysis using BioRank described here mirrors (with some exceptions) the approach used in the assessment of the WorldSID 50th ATD. See, e.g., 80 FR 78522, 78538 (Dec. 16, 2015) (New Car Assessment Program Request for Comments); 71 FR 75304 (Dec. 14, 2006) (final rule for ES–2re Side Impact Crash Test Dummy 50th Percentile Adult Male); 71 FR 7534 (Dec. 14, 2006) (final rule for SID–IIs Side Impact Crash Test Dummy 5th Percentile Adult Female).

¹⁴³ The standard deviation is a statistic that measures the dispersion of a dataset relative to its mean.

of test conditions and body regions.¹⁴⁴ The BioRank system was developed to minimize subjectivity in the areas of corridor development, weighting, and scoring. Another method NHTSA considered is correlation and analysis (CORa), which may be a useful tool to carry out quantitative analysis.¹⁴⁵ However, the vast array of tunable parameters in the software can result in unintentional subjectivity and poor reproducibility. Further, there are no known and accepted relationships between CORa scores and biofidelity classifications. Accordingly, we evaluated biofidelity using BioRank.

We note that because many of the biofidelity test conditions utilize specialized instrumentation or test equipment, they are not intended to be carried out as certification or qualification tests conducted between crash tests or sets of crash tests to confirm that specified ATD response requirements are met. Instead, due to its relative complexity, biofidelity testing is carried out at the ATD design stage to assess the biofidelity of the design. Simplified and standardized versions of the biofidelity test conditions have been developed as qualification procedures for some body regions. Because the qualification response requirements are

based on the expected variation in response of the ATD, not the underlying human response, the qualification requirements specify a much smaller allowable range in response than the biomechanical design targets. Therefore, it is expected that all THOR–50M units that meet the specifications of the qualification procedures would demonstrate similar biofidelity. The proposed qualification response requirements are discussed in Section V.

A full description of NHTSA's biofidelity testing and analysis can be found in the docketed biofidelity report.¹⁴⁶ We note that there are no separate discussions in the report for the shoulder, spine, or pelvis. Impact biofidelity of the spine and pelvis, as well as the dynamic biofidelity of the shoulder, are intrinsically evaluated as part of the whole-body biofidelity sled test series.¹⁴⁷ Shoulder biofidelity has also been assessed quasi-statically and found to be more similar to the human volunteer corridors than existing ATDs. NHTSA is finalizing a report on the alternate shoulder design, which includes the biofidelity evaluation described here; once complete, this report will be published to the research docket.

NHTSA believes that the THOR–50M is sufficiently biofidelic for incorporation into Part 572. The biofidelity report shows that the THOR–50M exhibits overall internal and external BioRank scores of below 2.0. See Table 7. Both internal and external BioRank scores are lower than those of the HIII–50M, which is defined in Part 572 (Subpart E) and used in regulatory and consumer information frontal impact crash testing. At the body region level, the internal and external BioRank scores for THOR–50M are all below 2.0 except for neck internal biofidelity and abdomen external biofidelity. The THOR–50M BioRank score for the neck and abdomen external biofidelity are, however, lower (better) than those for the HIII–50M. Overall, the internal BioRank scores for the THOR–50M were lower than those of HIII–50M in 5 of the 7 body regions evaluated, and THOR–50M external BioRank scores were lower than those of HIII–50M in 6 of the 7 body regions evaluated. Thus, the THOR–50M has generally improved biofidelity in the individual body region tests, which improves the accuracy of injury predictions. The THOR–50M and the HIII–50M have comparable quantitative biofidelity in the whole-body sled test conditions.¹⁴⁸

TABLE 7—BODY REGION INTERNAL AND EXTERNAL BIORANK SUMMARY

Body region	THOR–50M		HIII–50M	
	Internal	External	Internal	External
Head	0.155	1.143	0.013	6.640
Neck	2.155	1.677	2.185	4.318
Thorax	0.917	0.948	1.603	2.070
Abdomen	1.470	2.803	1.629	3.474
KTH	1.400	1.731	3.875	6.667
Lower Extremity	1.349	0.871	0.832	1.108
Whole-body	1.472	1.989	1.576	1.780
Overall	1.274	1.594	1.673	3.722

Since a majority of the test conditions involved pure frontal loading, and several involved oblique and lateral loading (neck lateral flexion, neck torsion, lower thorax oblique, Gold Standard 3, and Far Side Oblique test conditions), these findings are expected to extend to frontal and frontal oblique

crash test conditions. The findings may not, however, extend to other loading conditions (such as pure lateral or rear impacts) without further research.

V. Qualification Tests

This NPRM proposes qualification tests (also referred to as qualification procedures) for THOR–50M. The

qualification procedures describe a series of impact tests performed on a fully-assembled dummy or dummy sub-assembly. The tests assess the components that play a key role in the dummy's performance in the intended application of frontal and frontal oblique crashes. We propose

¹⁴⁴ Rhule, D., Rhule, H., Donnelly, B. (2005) The Process of Evaluation and Documentation of Crash Test Dummies for Part 572 of the Code of Federal Regulations. 19th ESV Conference, Paper No. 05–0284, pp. 9–10.

¹⁴⁵ Gehre C, Gades H, Wernicke P (2009) Objective rating of signals using test and simulation responses. The 21st International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 09–0407, 2009.

¹⁴⁶ Parent, D., Craig, M., Moorhouse, K. 2017. Biofidelity Evaluation of the THOR and Hybrid III 50th Percentile Male Frontal Impact Anthropomorphic Test Devices. Stapp Car Crash Journal, 61, 227–276, available at: <https://www.regulations.gov/document/NHTSA-2019-0106-0004>.

¹⁴⁷ The qualitative biofidelity of the shoulder is also discussed in the Biofidelity Report, where the role of the shoulder in belt retention (or lack thereof) is discussed qualitatively. See p. 272–273.

¹⁴⁸ This finding has been confirmed by independent research; a 2018 study showed that the HIII–50M and THOR–50M demonstrated similar biofidelity scores in a sled test environment representing a production vehicle. See Albert, Devon L., Stephanie M. Beeman, and Andrew R. Kemper. "Occupant kinematics of the Hybrid III, THOR–M, and postmortem human surrogates under various restraint conditions in full-scale frontal sled tests." Traffic Injury Prevention 19.sup1 (2018): S50–S58.

qualification tests for the head, face, neck, upper thorax, lower thorax, abdomen, upper leg, knee, and lower leg. For some body regions (such as the face) we propose a single test condition (also referred to as a test mode), while for other body regions (for example, the neck) we propose a series of different test conditions.

Each qualification test condition consists of test procedures, test parameters, and acceptance intervals. The test procedures describe a detailed series of steps that must be carried out to perform the test. Test parameters describe specific aspects of the dummy's response. Acceptance intervals (or qualification targets) are specified for each test parameter. Acceptance intervals are a typically pair of numeric values (a minimum value and maximum value) within which the dummy response must fall in order to pass, but can also represent a minimum or maximum value of the response. For instance, one of the tests involves striking the head with an impactor and measuring the head's acceleration, which must be within the acceptance interval 117 ± 11.7 Gs.

The qualification tests mirror the dummy loading patterns observed in frontal crash tests, including full frontal, oblique, and offset modes. For the neck assembly, we have specified separate requirements in flexion, extension, and lateral flexion. These bending modes have all been observed in crash testing. Additionally, a torsion test is prescribed for the neck since it also twists along its long axis to some degree. For the feet and ankles, tests in inversion, eversion, dorsiflexion, and axial loading through the tibia are specified to account for the various injurious loads that have been observed in crash tests. For the head, face, upper and lower thorax, abdomen, upper legs, and knees, we have only prescribed impact tests to anterior aspects since injurious loads pass primarily through those aspects during crash testing. The impact speeds and probe masses have been selected to demonstrate that the various body segments work properly at energy levels at or near those associated with high injury risks. For measurements not associated with an injury criterion, energy levels are chosen to exercise the dummy approaching its functionality limits, but without causing damage.

The qualification tests ensure that the dummy is functioning properly. There are a few inter-related aspects to this. One is that qualification tests ensure that dummy components and sensors are properly assembled and functioning. Qualification tests monitor the response of components that may have become

loosened or misaligned since initial assembly. For each test, certain dummy sensors and signal characteristics (such as the magnitude and timing) have been specified as qualification targets. Loose or misaligned parts may become evident when a signal does not conform to the prescribed signal characteristics. By monitoring these sensors, the qualification tests ensure that the dummy is functioning properly. The tests also ensure that the sensors themselves are working properly. Another aspect is that qualification tests help identify components that have deteriorated over time, preventing the dummy from meeting the qualification targets; such parts need to be replaced or refurbished. Many of the qualification test protocols are very similar to the dynamic tests used to assess biofidelity. This helps to ensure that a qualified dummy is also a biofidelic dummy. Finally, they ensure that the dummy or particular sub-assembly is responding in a uniform and expected manner; if it is not, certain dummy components might need to be tuned or adjusted to obtain a response within the qualification targets.

NHTSA's experience has shown that the impact tests on body segments are needed to ensure uniformity of dummy responses in a subsequent vehicle crash test. In other words, full conformance to part and assembly specifications (in accordance with the drawings and PADI) is not enough to guarantee a uniform dummy response in a crash test.¹⁴⁹ Qualification tests have proven reliable and sound in qualifying NHTSA's other test dummies. Moreover, some of the proposed qualification tests use the same test equipment as other ATDs, thus minimizing the amount of new qualification equipment needed by test laboratories that may already have such equipment in place for qualifying other ATDs. Meeting the qualification tests helps ensure that the dummy is capable of responding properly in a compliance or research test. This in turn helps to ensure that the dummy is an objective test device suitable for the assessment of occupant safety in compliance tests specified in Federal Motor Vehicle Safety Standards, and for other testing purposes.

NHTSA proposes setting the qualification targets at $\pm 10\%$ of the mean response for each qualification parameter as reported in the qualification test R&R study (discussed in Section VI). In that study we subjected multiple dummies to repeated

tests in each test condition at multiple test laboratories. The repeatability testing and analysis for the qualification tests is described in more detail in Section VI.A. We believe that 10% is wide enough to account for normal variations in ATD and laboratory differences, and narrow enough to ensure consistent and repeatable measurements in standardized testing with the ATD. This is also consistent with the qualification limits for the other Part 572 ATDs. For example, for the Hybrid III 10-year-old child dummy, the acceptance intervals are, on average, set at $\pm 9.9\%$ from the nominal midpoint, with a low of 8.4% (neck rotation in the neck extension test) and a high of 10.8% (in the neck moment in the extension test and chest deflection in the thorax impact test).¹⁵⁰ For all Part 572 ATDs, the average acceptance interval is $\pm 11\%$.

We also considered setting the qualification targets at plus or minus two standard deviations from the mean response observed in the testing reported in the repeatability and reproducibility study. This would have narrowed the acceptance interval for almost all responses, some of which would have been unreasonably narrow. For instance, the head impact test results in the repeatability and reproducibility study were very uniform, with a CV for peak force of 0.9% . If the acceptance interval for peak force were set to plus or minus two standard deviations ($\pm 1.8\%$), 24 of the 26 trials would have resulted in a pass; if it were set to $\pm 2.5\%$, all 26 trials would have resulted in a pass. This result may have been a function of using only three THOR-50M units in the test series, all of which were brand new when we tested them. Therefore, we propose a greater allowance of $\pm 10\%$ for all qualification requirements to account for slight variations that may arise from equipment and testing variations at different test labs as well as a future population of THOR-50M units from dummy manufacturers in which lot-to-lot differences in the fabrication of parts from the same manufacturer may exist. It also allows for slight changes to individual THOR-50M units over time, either due to aging of polymeric components or wear and tear under normal use. Table 8 summarizes the proposed THOR-50M qualification requirements.

¹⁴⁹ At the same time, conformance to a qualification requirement is not a substitute for parts that do not conform to drawing specifications.

¹⁵⁰ HIII-10C, Subpart T.

TABLE 8—PROPOSED THOR–50M QUALIFICATION REQUIREMENTS

Test	Measurement	Units	Nominal target	Acceptance interval
1. Head Impact	Peak Probe Force	N	5580	5022–6138
	Peak Head CG Resultant Acceleration	G	117.0	105.3–128.7
2. Face Impact	Peak Probe Force	N	7098	6378–7796
	Peak Head CG Resultant Acceleration	G	138	124–152
3. Neck Flexion	Peak Upper Neck My	N-m	31.0	27.9–34.1
	Upper Neck Fz Most Positive Value Prior to 40 ms	N	860	774–946
	Peak Head Angular Velocity ω_y (relative to earth)	deg/sec	1975	1777–2172
	Peak Head Rotation (relative to pendulum)	deg	64.5	58.1–71.0
4. Neck Extension	Peak Upper Neck My	N-m	23.0	20.7–25.3
	Peak Upper Neck Fz	N	2918	2626–3210
	Peak Head Angular Velocity ω_y (relative to earth)	deg/sec	2061	1855–2267
	Peak Head Rotation (relative to pendulum)	deg	65.0	58.5–71.5
5. Neck Lateral	Upper Neck Mx first peak after 40.0 ms	N-m	49.7	44.8–54.7
	First Peak Head Angular Velocity ω_x (relative to earth)	deg/sec	1362	1226–1498
	Peak Head Rotation (relative to pendulum)	deg	41.7	37.6–45.9
6. Neck Torsion	Peak Upper Neck Mz	N-m	41.4	37.3–45.6
	First Peak Upper Neck Angular Velocity ω_z (relative to earth)	deg/sec	1390	1251–1529
	Peak Neck Fixture Rotation	deg	47.9	43.1–52.7
7. Upper Thorax	Peak Probe Force	N	3039	0–3039
	Peak Upper Resultant Deflection	mm	53.6	48.3–59.0
	Difference Between Peak Left & Right Resultant Deflections.	mm	0	–5 to 5
	Force at Peak Resultant Deflection	N	2677	2409–2944
8. Lower Thorax	Peak Probe Force	N	3484	3136–3832
	Resultant Deflection at Peak Force	mm	50.9	45.8–56.0
9. Lower Abdomen	Peak Probe Force	N	2918	2626–3210
	Lower Abdomen X-axis Deflection at Time of Peak Force	N	83.0	74.7–91.3
	Difference Between Peak Left & Right X-axis Deflections	mm	0	–8 to 8
10. Upper Leg	Peak Probe Force	N	8333	7500–9166
	Peak Femur Force, Fz	N	4920	4428–5412
	Peak Resultant Acetabulum Force	N	2738	2464–3012
11. Knee	Peak Femur Z-axis Force	N	6506	5855–7156
	Knee Deflection at Peak Femur Force	mm	20.2	18.2–22.2
12. Ankle Inversion	Peak Lower Tibia Fz	N	505	454–555
	Peak Ankle Resistive Moment	N-m	39.1	35.2–43.0
	Peak Ankle X-axis Rotation	deg	34.5	31.0–37.9
13. Ankle Eversion	Peak Lower Tibia Fz	N	571	514–629
	Peak Ankle Resistive Moment	N-m	43.0	38.7–47.3
	Peak Ankle X-axis Rotation	deg	29.6	26.6–32.5
14. Ball of Foot	Peak Lower Tibia Fz	N	3170	2853–3487
	Peak Ankle Resistive Moment	N-m	55.3	49.8–60.8
	Peak Ankle Y-axis Rotation (in dorsiflexion)	deg	33.8	30.4–37.2
15. Heel	Peak Lower Tibia Fz	N	3162	2846–3478

Note: For comparison purposes, unless otherwise noted, only positive values are shown for the Nominal Target and Acceptance Range. Some targets, such as Neck Flexion Angular Velocity ($\omega_y = -1362$ deg/sec), are defined by negative values.

The proposed qualification requirements are the same as the 2018 version except for the upper leg; this is discussed in the section below for the upper leg.

Euro NCAP TB026 explicitly adopts NHTSA’s 2018 qualification procedures¹⁵¹ with a couple of differences. First, there are a few differences between the proposal and TB026 with respect to the tests or test parameters. TB026 specifies somewhat different qualification metrics for the upper thorax test and does not include a face impact test. TB026 prescribes the upper leg test described in NHTSA’s 2018 qualification procedures, which we are proposing to update. And,

because TB026 specifies the HIII–50M lower extremities, the corresponding qualification tests are not the same as those proposed. Second, although TB026 adopts the rest of the 2018 qualification test procedures and test parameters, it specifies acceptance intervals that differ from the proposed acceptance intervals with respect to both the width and midpoint of the interval. While the proposed acceptance intervals are $\pm 10\%$ around the mean (as calculated from our R&R testing), the width of the acceptance intervals specified in TB026 range from 1% to 10%, with many of them less than 10%. In addition, the midpoint of these intervals differs from the means NHTSA calculated based on its R&R testing. For nine of the parameters, the TB026

specifications are fully contained within the proposed acceptance intervals. Of the remaining parameters, there is a minimum of 82% overlap between the Euro NCAP specifications and the proposed acceptance intervals. Therefore, it is feasible, but not guaranteed, for a THOR–50M which meets the Euro NCAP acceptance intervals to also meet the proposed acceptance intervals. NHTSA has tentatively decided not to adopt narrower acceptance intervals, such as those specified in TB026, for the reasons given above. Moreover, NHTSA is unaware of the data on which the Euro NCAP specifications are based, whereas the proposed specifications are based on NHTSA’s carefully-controlled study. The differences between the proposed

¹⁵¹ § 2.1.

qualification tests and those specified in TB026 are discussed in more detail in the relevant sub-sections below. In addition, the proposed qualification test parameters and acceptance intervals and the corresponding TB026 values are summarized in Appendix G.

We propose to set out the qualification procedures in a separate document that would be incorporated by reference into Part 572. See Section XI, Incorporation by reference. This would be a departure from the other ATDs currently specified in Part 572, for which the qualification tests are set out in full in the regulatory text in each of the relevant paragraphs (corresponding to that ATD) in part 572. We are proposing a separate qualification procedures document for THOR–50M because the THOR–50M qualification procedures contain many photographs and diagrams that are not amenable to publication in the CFR; we believe this extra level of detail will be helpful for end users who are attempting to qualify the ATD.

NHTSA seeks comment on the proposed qualification tests. NHTSA also seeks any qualification data commenters are able to provide, as long as the data are from THOR–50M ATDs conforming to the 2023 drawing package and were collected following the April 2023 Qualification Procedures Based on any comments and data received. NHTSA might consider changing the qualification targets to reflect the larger population of THOR–50M units in the field. However, before doing so we would assess the effect that any change could have on the biofidelity of the dummy and the applicability of injury risk functions. We also seek comment on whether we should incorporate the qualification procedures by reference, or whether it would be preferable to locate a much-simplified set of qualification procedures directly in Part 572 and put additional detail and documentation in the Office of Vehicle Safety Compliance (OVSC) laboratory test manual or similar document that would not be incorporated by reference but instead provided as guidance to DOT contractors and other ATD end users.

A. Head Impact

The head qualification test is identical to the whole-body head impact biofidelity assessment, where a fully-assembled THOR–50M is seated on a table and impacted on the forehead with a 23.36 kg rigid impactor at 2.00 ± 0.05 m/s. This test serves as a surrogate for the isolated head drop test used by other ATDs; due to the construction of the head and neck of the THOR–50M ATD (specifically, the integration of the neck

spring cables into the skull), separation of the head from the neck is not feasible. The test assesses the performance of the head skin and CG accelerometers, which are used to calculate HIC₁₅.¹⁵² The probe force and the head CG resultant acceleration are measured and would have to be within the proposed acceptance intervals.

B. Face Impact

The face qualification test is identical to the face rigid disk impact biofidelity assessment, where a fully-assembled THOR–50M is seated on a table and impacted on the face with a 13 kg rigid impactor with a 152.4 mm diameter flat disk impact surface at 6.73 ± 0.05 m/s. This test assesses the impact response of the face, which is driven primarily by the face foam insert (Part No. 472–1401). Additionally, as this test is more severe than the head impact test, it assesses the head CG accelerometers (which are used to calculate HIC₁₅) at a level of severity closer to that expected from vehicle crash tests. FMVSS No. 208 specifies a maximum calculated HIC₁₅ value of 700 for the HIII–50M, and the average HIC₁₅ measurement from a set of 29 vehicle crash tests in either the full frontal rigid barrier or OMDB crash test modes was 285.¹⁵³ The head impact test, however, results in an average HIC₁₅ of 157 (probability of AIS 3+ injury of 0.05%), while the face impact is more severe, with an average HIC₁₅ of around 450 (probability of AIS 3+ injury of 3.5%). Therefore, compared to the head impact test, the face impact test is a better assessment of the head response at a severity level expected from vehicle crash tests, as it results in a HIC₁₅ that is closer to the current FMVSS No. 208 injury assessment reference value. During these tests, the probe force and the head center of gravity (CG) resultant acceleration are measured and would have to be within the proposed response corridors.

C. Neck

The proposed neck qualification test series, in which the entire head-neck assembly is removed from the ATD and affixed to the conventional Part 572 swinging pendulum to apply a prescribed impulse to the neck, includes six tests: flexion, extension, left lateral flexion, right lateral flexion, left torsion, and right torsion. The swinging

pendulum apparatus serves as a surrogate for the more complex neck biofidelity assessment, which is carried out in a sled test configuration. The neck qualification tests assess the collective performance of the molded neck column, the occipital condyle cam and associated bump stops, and the neck spring towers. In the process, the neck qualification tests assess the performance of the upper neck load cell, from which the Z-axis force and Y-axis moment are used to calculate Nij.¹⁵⁴ The neck axial force, neck moment about the relevant axis, and neck rotation about the relevant axis are measured and would have to be within the proposed acceptance intervals. The neck flexion and extension qualification tests are similar to those specified for the HIII–50M¹⁵⁵ in that they use the same pendulum and similar deceleration specifications.

D. Upper Thorax

This test involves impacting the chest of a fully-assembled THOR–50M seated on a table with a rigid impactor. The upper thorax qualification test is configured similarly to that carried out on the HIII–50M,¹⁵⁶ using the same pendulum (23.36 kg, 152.40 mm diameter) to impact the mid-sternum, but at a lower impact velocity of 4.3 meters per second. This test assesses the dynamic thoracic response to sternal impact as well as the functionality of the upper left and upper right thoracic deflection instrumentation. This test condition is identical to the associated biofidelity assessment, though the qualification test uses only internal deflection measurements so that motion tracking or other external instrumentation is not required. Several measurements must be within the proposed acceptance intervals: the peak overall probe force, the peak upper left and upper right resultant deflections, the difference between the peak left and right resultant deflections, and the probe force at the peak left and right resultant deflections.

In the 2016 qualification procedures, the upper thorax qualification required individual X-axis and Z-axis deflection specifications for both the upper left and upper right thorax. This was revised in the 2018 qualification procedures by specifying the peak resultant deflection instead, which better aligns with the peak resultant deflection measure used to evaluate thoracic injury risk.¹⁵⁷

¹⁵² Craig, M., Parent, D., Lee, E., Rudd, R., Takhounts, E., Hasija, V. (2020). Injury Criteria for the THOR 50th Male ATD. *Regulations.gov* Docket ID NHTSA–2019–0106–0008, available at: <https://www.regulations.gov/document/NHTSA-2019-0106-0008>.

¹⁵³ The range was 104–1262 and the standard deviation was 210.

¹⁵⁴ Craig et al (2020), Injury Criteria for the THOR 50th Male ATD.

¹⁵⁵ 49 CFR 572.33 Neck.

¹⁵⁶ 49 CFR 572.34 Thorax.

¹⁵⁷ Craig et al (2020), Injury Criteria for the THOR 50th Male ATD.

Applying specifications on the resultant deflection instead of two individual components allows for a reduction in the overall number of required measurements, while still capturing the physical response of the dummy since the X-axis and Z-axis deflections are the primary components of the resultant deflection in this test condition.

The Euro NCAP qualification response requirements differ from the proposal in three ways. First, they include an additional parameter: the ratio of Z-axis to X-axis deflection. Second, they do not require a maximum difference between left and right peak resultant deflection, whereas the proposed qualification targets limit the left-to-right difference to 5 millimeters. Using the Euro NCAP targets, the difference between the left and right peak resultant deflections could be as high as 7.2 millimeters. Third, as noted above, the qualification targets are narrower than the proposed qualification targets.

NHTSA has tentatively decided not to specify the ratio of Z-axis to X-axis deflection because doing so would effectively revert to the 2016 approach of individual X-axis and Z-axis deflection requirements, which would increase the difficulty in meeting the qualification specification without a direct link to injury prediction, as the peak resultant deflection specification is of primary importance because it is the metric used in the calculation of thoracic injury risk.

NHTSA is aware that the upper thorax qualification specification has been a topic of frequent discussion within the International Standards Organization (ISO) working groups (particularly ISO/TC 22/SC 36, Safety and impact testing, Working Groups 5, Anthropomorphic Test Devices, and 6, Performance criteria expressed in biomechanical terms). NHTSA understands that those discussions have focused on potential modifications to the drawing package to meet the upper thorax qualification response requirements (in the context of testing related to Euro NCAP). Those modifications—specifically, the shorter rib guide, the individual rib performance test, and changes in the area of the coracoid process—have been discussed as describe in Section III, Design, Construction, and Instrumentation.¹⁵⁸ NHTSA does not

believe the modifications are necessary to meet the proposed upper thorax qualification requirements because NHTSA's repeatability and reproducibility testing showed that those requirements were achieved by three different THOR-50M units at three different test labs. See Section VI, Repeatability and Reproducibility. Moreover, it is not clear whether these changes would preclude a THOR-50M from meeting the proposed qualification requirements, though since the Euro NCAP specifications are narrower, any variation caused by these changes may be within the NHTSA's proposed acceptance intervals. Before implementing any of these design changes, the performance of the prototype parts would need to be evaluated.

In an effort to further investigate these contemplated changes to THOR-50M, NHTSA analyzed its upper thorax qualification test data. NHTSA's limited analysis suggests that the difficulty meeting the Euro NCAP upper thorax qualification requirements might stem not from the dummy design, but from the smaller allowable range of peak resultant deflection and the addition of the deflection ratio corridor specified in TB026. However, it would be necessary to know how the Euro NCAP upper thorax qualification requirements were determined to carry out a complete analysis. This preliminary analysis is discussed in more detail in Appendix A.

E. Lower Thorax

The lower thorax qualification test is unique to the THOR-50M. This test involves impacting the lower thorax of a fully-assembled THOR-50M seated on a table with a rigid impactor. It is similar to the upper thorax qualification test, as it uses the same pendulum (23.36 kg, 152.40 mm diameter) at the same impact velocity (4.3 meters per second). The test assesses the dynamic impact response of the lower torso, to which the rib cage and the upper and lower abdomen assemblies contribute, while at the same time assessing the functionality of the lower left and upper right thoracic deflection instrumentation. The lower thorax qualification test is a simplification of the lower ribcage oblique impact biofidelity condition. In the biofidelity condition, the torso is rotated by 15 degrees and a chestband is used to measure external deflection. In the qualification condition, the torso is not rotated, but instead offset relative to the line of travel of the pendulum such that the pendulum is centered on the lower left or lower right anterior attachment point of the thoracic deflection

instrumentation. As in the upper thorax condition, the lower thorax qualification mode uses internal deflection measurements so that motion tracking or other external instrumentation is not required. During this test, the peak overall probe force and the peak resultant thoracic deflection at the time of peak probe force are measured and would have to be within the proposed acceptance intervals.

F. Abdomen

This test (which is unique to the THOR-50M) impacts the lower abdomen of a fully-assembled THOR-50M with a 177.8 mm by 50.8 mm rigid rectangular face impactor, weighing 32.00 kg, at 3.30 m/s. It was originally based on the lower abdomen rigid bar biofidelity condition, though several modifications were made over time to increase its objectivity and improve its utility as a qualification test. This test assesses the dynamic response of the lower abdomen, including the jacket, lower abdomen foam inserts, and lower abdomen bag, as well as the functionality of the abdominal deflection instrumentation. The peak overall probe force, the peak left and right X-axis abdomen deflection at the time of peak probe force, and the difference between the left and right X-axis deflection at the time of peak probe force are measured and would have to be within the proposed acceptance intervals.

G. Upper Leg

The upper leg qualification test assesses the dynamic impact performance of the knee flesh, knee flesh insert, and femur compression element, while evaluating the functionality of the femur and acetabulum load cells. The full THOR-50M is seated on a table with a posterior restraint adjacent to the pelvis flesh and impacted at the knee by a 12.00 kg impactor with a 76.2 mm diameter rigid disk impact surface at 3.3 ± 0.05 m/s parallel to the femur. The peak probe force, peak femur Z-axis force, and peak resultant acetabulum force would have to be within the proposed acceptance intervals.

This differs from the test procedure in the 2018 Qualification Procedures Manual in the THOR-50M research docket. The 2018 draft qualification test procedures for impacting the knee specifies the use of a 5.0 kg impactor at 2.6 m/s. NHTSA's repeatability and reproducibility testing of the qualification procedures, however—which used the 2018 draft procedures—resulted in coefficients of variation

¹⁵⁸ In addition, some members of Working Group 5 have observed variations in the ATD responses in the upper thorax qualification tests that have led to difficulties in meeting the Euro NCAP qualification specifications, and have suggested that this may result from variation in the spine flex joint, potentially due to material that was not as hard as the specification called for.

(CVs)¹⁵⁹ above 10%, particularly for the peak resultant acetabulum force. NHTSA therefore conducted a detailed review of the qualification test procedure.¹⁶⁰ This review led NHTSA to conclude that the impact energy was unrealistically low, leading to two problems. First, the low test energy did not load the acetabulum at a magnitude similar to that produced in vehicle crash tests or associated with a meaningful injury risk. This is particularly important because the upper leg test mode is the only qualification test that assesses the acetabulum load cells, and peak resultant acetabulum force is used in calculating the acetabulum injury risk. Second, and relatedly, the measurement values were so low, it was difficult to distinguish the signal from the noise.

Accordingly, NHTSA revised the test parameters by increasing the impactor mass and velocity and installing a backer plate behind the pelvis to prevent any rearward motion during the test. These are the parameters that we are proposing and for which data is presented (and acceptance intervals calculated) in the qualification repeatability and reproducibility study. As we explain in Section VI.A, the revised test procedures resulted in repeatability and reproducibility CVs of 5% or lower for all test measurements including peak resultant acetabulum force. Additionally, the average acetabulum force recorded in the improved upper leg qualification is more representative of the forces recorded in frontal rigid barrier and OMDB vehicle crash tests, and represents a non-negligible injury risk.

H. Knee and Lower Leg

NHTSA is also proposing qualification tests for the knee and lower leg (ankle, ball of foot, and heel).

The knee qualification test is a simplification of the knee shear biofidelity condition. The test assesses the response of the anterior-posterior translation of the tibia with respect to the femur at the knee joint, the translational resistance of the knee slider and the stiffness of the stop assembly, and the functionality of the knee slider string potentiometer. To conduct the knee impact test, the left or right knee assembly (detached at the base of the femur load cell) is removed from the ATD and mounted to a rigid surface, and a load distribution bracket

is attached to the knee slider assembly. The load distribution bracket is impacted with a 12.00 kg impactor with a 76.2 mm diameter rigid disk impact surface at 2.20 ± 0.05 m/s. Unlike the HIII-50M knee slider test, no foam pad is used on the impact surface for this test. During these tests, the femur Z-axis force and knee slider deflection at peak femur force are measured and would have to be within the proposed acceptance intervals.

We propose four different qualification tests to assess the lower leg responses: ankle inversion, ankle eversion, ball of foot impact, and heel impact. All four test setups are similar. In each, the lower legs are removed from the dummy and each leg is tested separately. The leg is affixed to a rigid fixture and struck by a pendulum parallel to the tibia. The alignment of the pendulum differs for each test: for the heel impact, it is in-line with the tibia; for the ball of foot impact, it produces dorsiflexion of the foot; for the inversion impact; it is offset medially from the tibia; for the eversion impact, it is offset laterally from the tibia. For the inversion and eversion impacts, the shoe is removed and replaced with a special striker plate that interfaces with the pendulum.

Euro NCAP TB026 specifies different qualification requirements for the knee and lower leg because TB026 specifies that the THOR-50M be fitted with the HIII-50M knee and lower leg.

VI. Repeatability and Reproducibility

Any ATD that is to be used for Federal regulatory testing must have an acceptable level of repeatability and reproducibility to ensure confidence in the responses provided by the dummy. In the context of dummy evaluation, repeatability refers to the similarity of responses from a single dummy when repeatedly subjected to a particular test condition. Reproducibility refers to the similarity of the responses from multiple dummies repeatedly subjected to a particular test condition. NHTSA also evaluated the repeatability and reproducibility of the qualification tests themselves, in addition to the dummy. To evaluate whether the THOR-50M ATD yields consistent results, NHTSA undertook an extensive series of testing.

NHTSA systematically investigated the repeatability and reproducibility (R&R) of the THOR-50M by conducting an extensive series of qualification and sled tests. Qualification test measurements are especially useful for evaluating dummy R&R because they are relatively simple tests on individual dummy components that can be tightly controlled so that variability in the test

measurements is more likely to come from the dummy than from other potential sources of variability, such as the test procedures or vehicle structures and materials. Sled testing is useful because it offers insight into the dummy's performance as a complete system in an environment similar to that of an actual vehicle—*e.g.*, the consistency of its kinematics, its impact response as an assembly, and the integrity of the dummy's structure. Sled tests are therefore more challenging for the dummy, while at the same time much more tightly controlled than a vehicle test, which does not provide a desirable environment for R&R testing due to the uncontrollable variation in vehicle structural materials and manufacturing variability. Qualification and sled tests together provide a basis for assessing whether the dummy will yield consistent results when it is ultimately used in full-scale vehicle tests. NHTSA's R&R testing also served several other important functions, such as developing the qualification corridors and further validating the usability and durability of the dummy.

NHTSA's R&R analysis of qualification and sled testing is briefly summarized in the next two sections. For more detailed information, the reader is referred to the docketed report "THOR-50M Repeatability and Reproducibility of Qualification Tests" (R&R Report).¹⁶¹

A note about dummy reproducibility: At the time NHTSA conducted this R&R testing (both qualification tests and sled tests) it only owned—and tested—THOR-50M units manufactured by Humanetics. Therefore, the reproducibility analyses reported here concerned dummy reproducibility (same lab, different dummies) and test reproducibility (same dummy, different labs).¹⁶² However, another aspect of reproducibility is whether dummies fabricated by different manufacturers perform in a uniform manner. To this end, NHTSA has purchased THOR-50M units from JASTI, Cellbond, and Kistler,

¹⁶¹ National Highway Traffic Safety Administration (2022). THOR-50M Repeatability and Reproducibility of Qualification Tests, May 2021, available at https://downloads.regulations.gov/NHTSA-2019-0106-0009/attachment_2.pdf. We note that for the sled test R&R analysis, there are no previously-published reports that provide this analysis. However, this analysis is provided in the paragraphs below on sled testing (and in the relevant appendices) and the underlying data is available in the NHTSA crash test database in either the biomechanics or vehicle paragraphs (the specific location is provided in the relevant discussion below).

¹⁶² NHTSA did not examine lab-to-lab reproducibility of the sled tests.

¹⁵⁹ See *infra* Section VI.A.

¹⁶⁰ Millis, W. (2021). An Improvement to the THOR-50M Upper Leg Qualification Test Methodology. 2021 SAE Government-Industry Digital Summit, available at: <https://www.nhtsa.gov/node/103666>.

and may test with these units prior to the final rule.

A. Qualification Tests

NHTSA has completed an R&R study of the qualification tests. This study has three main purposes. One is to assess the repeatability and reproducibility of the dummy. Another is to determine the acceptance intervals for the qualification tests. Third, is to assess the R&R of the qualification tests themselves. Assessing the R&R of the qualification tests is important for at least two reasons: it aids in determining whether the variation in measurements are attributable to the dummy, the test procedures, or the testing practices of different laboratories, and it helps ensure that the qualification test procedures themselves are as consistent and replicable as possible so that, ultimately, the test measurements obtained in a compliance test are uniform across dummies and test laboratories. In addition to these main purposes, the qualification R&R testing also helped NHTSA to identify and resolve potential issues with the qualification procedures; reveal and resolve potential issues with, and functional limitations of, the dummy.

Below, we first summarize our methodology for the qualification R&R analysis, and then proceed to briefly summarize the results of the R&R assessment for each THOR-50M body region.

Methodology

The proposed qualification tests were carried out on three THOR-50M ATDs manufactured by Humanetics. The ATDs conformed to the proposed drawing package. Every ATD was subjected to five repeat tests in each qualification test condition at NHTSA's Vehicle Research and Test Center (VRTC) and one of the three dummies was tested at two other labs, Humanetics and Calspan (with some exceptions as described in the following paragraphs). All tests were used in development of the proposed qualification acceptance intervals, with some exceptions as explained below where the input velocity did not meet

the specification. For qualification test conditions where one ATD component is tested in both the left and the right direction, only the left direction is included in the analysis, as the dummy design is symmetric and not expected to differ between the two sides. For qualification test conditions in which multiple ATD components are tested, data from the left and right tests or measurements are combined.

We evaluated R&R of both the dummy and the qualification tests using a statistical analysis of variance referred to as the coefficient of variation (CV). The CV approach was first introduced by NHTSA as a means for evaluating dummy repeatability when the original subpart B Hybrid II 50th percentile male ATD was proposed.¹⁶³ Since then, the agency has used this approach for other Part 572 rulemakings.¹⁶⁴ The CV is a measure of variability expressed as a percentage of the mean. It is defined as the percentage of the sample standard deviation divided by the mean of the data set:

$$CV = \frac{s}{\bar{x}} \times 100\%.$$

In the qualification test series, the data points of each trial are considered on their own and not as being representative of a large population. Thus, the sample-based standard deviation is applied in which s is an estimate of the standard deviation based on a sample.¹⁶⁵ It is computed using the following formula, where \bar{x} is the average value of the trials (sample mean) and n is the number of trials (sample size).

$$\sqrt{\frac{\sum(x - \bar{x})^2}{(n - 1)}}$$

For each qualification test parameter (e.g., head impact peak probe force) specified for each test condition (e.g., head impact), we computed the mean, standard deviation, and coefficient of variation. More specifically, to investigate dummy repeatability and test repeatability, we calculated these summary statistics for the five tests of each test condition performed on each of the three dummies at VRTC. To investigate dummy reproducibility, we pooled the data for the three dummies tested at VRTC. Finally, to investigate test reproducibility, we pooled the data for the dummy that was tested at VRTC, Calspan, and Humanetics.

We used the following approach to assess R&R:

- CV <5%: No further investigation. We believe that a set of responses with a CV below 5% indicates a highly repeatable and reproducible condition.
- 5% ≥ CV ≤ 10%: sources of variability investigated.
- CV >10%: Test procedure thoroughly reviewed and dummy(ies) inspected.

When the CV was greater than or equal to 5%, we investigated the source of the variability. In all cases, we were able to determine the source of the variation with reasonable confidence. Once NHTSA had refined the qualification test procedures it only obtained a CV greater than 10% in two instances—repeatability of the face foam, and test reproducibility in one measurement in the neck extension mode. Prior to refining the test procedures, NHTSA obtained a CV greater than 10% for the upper leg test. A full investigation led to a new and improved test procedure. That new test procedure is reflected in the R&R report, and the resulting CVs all less than 10%. Table 9 and Table 10 summarize the CVs that we calculated for each test parameter for each qualification test condition. Table 11 summarizes the variability sources and resolutions seen in the qualification R&R test series.

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¹⁶³ 40 FR 33466 (Aug. 8, 1975).

¹⁶⁴ See, e.g., 85 FR 69898, 69904-69905 (Nov. 3, 2020) (final rule for Q3s ATD).

¹⁶⁵ The population-based standard deviation, which is always lower than the sample-based standard deviation, is not appropriate because only a limited number of NHTSA-owned THOR-50M units were tested, and the tests were carried out at a limited number of test facilities.

Table 9. Qualification Repeatability and Reproducibility Coefficients of Variation (Head to Abdomen).

Test Parameter	Repeatability (Dummy and Test)			Reproducibility	
				Dummy	Test
	ATD # DL9207	ATD # DO9798	ATD # DO9799	Based on all three ATDs	Based mostly on ATD # DO9799

Head					
Peak probe force	0.3	0.7	0.7	0.5	1.0
Peak head CG resultant acceleration	1.6	0.6	1.7	1.4	3.7
Face					
Face foam serial number	#010	#011	#012	All	N/A
Peak probe force	8.6	10.1	7.5	8.4	N/A
Peak head CG resultant acceleration	9.1	12.1	7.6	9.3	N/A
Neck					
Neck serial number	EB6007	EB6006	EB6005	All	EB6007
Neck Flexion					
Peak upper neck Y-axis moment	5.8	5.1	3.0	5.4	4.5
Peak upper neck Z-axis force, max. before 40ms	6.0	2.5	2.3	4.2	7.5
Peak head Y-axis angular velocity	0.8	0.9	2.2	1.9	2.0
Peak head rotation relative to pendulum	0.8	1.6	1.0	2.3	2.5
Neck Extension					
Peak upper neck Y-axis moment	3.2	2.7	0.7	3.9	5.6
Peak upper neck Z-axis force	1.4	3.0	1.7	3.7	12.2
Peak head Y-axis angular velocity	1.4	2.4	1.7	2.7	4.4

Peak head rotation relative to pendulum	0.9	1.6	0.5	1.7	2.0
Neck Lateral Flexion					
Peak upper neck X-axis moment	0.9	0.8	1.4	1.9	4.1
Peak head X-axis angular velocity	0.7	1.1	3.4	2.8	3.0
Peak head rotation relative to pendulum	1.7	1.2	2.5	2.6	2.8
Neck Torsion					
Peak upper neck Z-axis moment	1.1	0.6	1.4	2.5	1.5
First peak head Z-axis angular velocity	1.3	1.5	2.0	2.5	4.5
Peak neck fixture rotation	1.7	1.2	3.1	3.5	1.2
Upper Thorax					
Peak probe force	1.3	1.7	2.7	2.3	2.8
Peak upper left/right resultant deflection	1.7	1.3	1.8	3.7	3.2
Force at upper left/right peak resultant deflection	1.3	1.5	2.9	2.2	2.3
Lower Thorax					
Left/right resultant deflection at peak force	2.0	5.2	1.8	4.4	6.6
Peak probe force	2.4	1.9	1.9	3.4	5.2
Abdomen					

Abdomen serial number	#1	#2	#3	All	#3
Peak probe force	1.6	1.1	3.3	2.3	3.4
Left/right abdomen X-axis deflection at peak force	5.7	5.2	5.0	5.3	5.5

Table 10. Qualification Repeatability and Reproducibility Coefficients of Variation (leg).

Test Parameter	Repeatability (Dummy and Test)			Reproducibility	
	ATD # DL9207	ATD #	ATD #	Dummy	Test
		DO9798	DO9799	All	ATD #

Upper Leg					
Peak probe force	1.7	2.9	0.8	4.6	4.1
Peak femur Z-axis force	2.2	4.5	2.3	4.7	3.8
Peak resultant acetabulum force	3.6	4.4	3.3	4.2	5.0
Knee					
Peak femur Z-axis force	1.1	0.6	2.6	5.0	5.9
Knee deflection at peak femur Z-axis force	1.9	0.7	1.4	1.8	2.1
Lower Leg					
Lower leg serial number	DL0202	DL5405	069	All	DL0202, DL5405
Ankle Inversion					
Peak lower tibia Z-axis force	3.0	4.1	4.0	3.7	5.3
Peak ankle resistive moment	3.3	4.5	4.8	4.8	4.4
Peak ankle X-axis rotation	1.3	1.3	2.4	1.7	1.7
Ankle Eversion					
Peak lower tibia Z-axis force	3.8	3.4	0.4	5.7	6.0
Peak ankle resistive moment	4.0	3.8	0.6	4.1	5.1
Peak ankle X-axis rotation	1.5	1.4	0.9	2.0	3.5
Ball of Foot					
Peak lower tibia Z-axis force	1.5	0.3	0.5	2.3	4.8
Peak ankle resistive moment	0.8	1.4	0.7	1.9	6.9
Peak ankle Y-axis rotation (in dorsiflexion)	1.1	0.3	0.7	2.2	1.9
Heel Impact					
Peak lower tibia Z-axis force	0.2	0.4	1.6	6.4	5.9

Light shading: $5\% \geq CV \leq 10\%$

Dark shading: $CV > 10\%$

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TABLE 11—SUMMARY OF QUALIFICATION TEST VARIABILITY SOURCES AND RESOLUTIONS

Test mode	Source of variability; control solution
Head	None.
Face	Face foam degradation occurs cumulatively with successive impacts; monitor and swap out foam as needed.
Neck Extension	The inverse relationship between My and Fz may be balanced by adjusting the input pulse through the selection of the pendulum’s honeycomb cell configuraton.
Neck Flexion	For a new molded neck, My and Fz may be elevated in initial test only. Also, the pendulum’s honeycomb cell configuration may need attention to control input pulse.
Neck Lateral	None.
Neck Torsion	None.
Upper Thorax	None.
Lower Thorax	The asymmetric test setup requires a high level of diligence from operator in aligning the dummy with the probe.
Abdomen	Operator diligence is needed to ensure a symmetric test setup. Otherwise, right vs. left discrepancies in force and deflection measurements will occur.
Upper Leg	If a high femur Fz occurs, a test lab may need to experiment with set-ups and dummy positioning (within allowable tolerances).
Knee	Low femur Fz measurements may be resolved at the test labs by experimenting with setups and dummy positioning.
Ankle Inversion	Ankle inversion and eversion tests are run on the same apparatus and are nearly identical. The ankle moment, tibia Fz, and ankle rotation may be slightly low in an initial qualification test if there has been an extended period of non-use of the Ensolite pad on the test fixture. This is only a concern if the tibia force and moment are just below the upper qualification limits, since subsequent tests may be expected to produce slightly higher moments and forces (which might be out of the qualification range). Labs can simply perform an additional test to confirm that the response of the ankle is within the requirements.
Ankle Eversion	
Ball of Foot	Test labs may need to adjust their set-ups and fixtures (within allowable tolerances) to attain a reponse within 10% of the target for ankle moment.
Heel	In cases where passing qualification results cannot be achieved, a test lab may need to replace the molded shoe assembly (472-7800-1 (left) or -2(right)) and/or the upper tibia complaint bushing assembly (472-7315) in order to attain a peak lower tibia Fz within 10% of the target.

Our investigation of the sources of variability also gives us additional confidence that the proposed acceptance intervals ($\pm 10\%$ of the mean response reported in the R&R study) are both achievable and sufficient to ensure that the dummy is providing uniform responses. In NHTSA’s testing, when the CV was below 5%, the responses in all the tests were always within the proposed acceptance intervals. When the CV exceeded 5%, however, we observed a response outside the proposed acceptance interval in at least one test. When the CV exceeded 10%, several tests were outside the qualification corridor.

NHTSA seeks comment on this methodology. Although the qualification R&R study utilizes only NHTSA’s test data, NHTSA is open to considering qualification data provided by commenters in the finalization of the qualification specifications, provided that the data are from THOR-50M ATDs conforming to the 2023 drawing package and collected following the proposed Qualification Procedures.

Head Impact

In the head impact qualification test mode, all CVs for repeatability and

reproducibility were below 5%, and the responses in all the tests were within the proposed qualification acceptance intervals.

Face Impact

We used a slightly different approach to evaluating the R&R of the face than we did for the other qualification tests. Our approach was motivated by two characteristics of the THOR-50M face.

First was the response of the face foam. The impact response of the face is driven primarily by the face foam insert, which is constructed of a memory foam that necessitates an extensive recovery period after a dynamic impact; the THOR-50M Qualification Procedures specifies at least 24 hours of recovery between tests. Even with this extended recovery period, however, the foam progressively degrades after each impact so that the peak probe force and peak head resultant acceleration increases with each test. We were able to conduct eight to nine tests with a new face foam insert before the face fell outside the upper bound of the face rigid disc impact biofidelity corridor (4,400 N to 8,200 N).

Second, because the face foam degrades, any variations in the dummy

response are likely to be masked by the significant variations caused by the foam. That is, most of the observed variation in the face qualification test is essentially due to the face foam response; any contributions of other components or lab-to-lab differences were negligible.¹⁶⁶

In light of these characteristics, we modified the R&R test methodology for the face impact tests. Our testing consisted of evaluating one dummy (DO9799) at VRTC, using three different new, unused, face foams (as opposed to testing three different ATDs); we deemed it unnecessary to test multiple ATDs because the variation in response was predominantly due to the face foam, not the ATD. We also did not test lab-to-lab variability (test reproducibility), because this would require testing the same face foam successively at multiple laboratories, which the degradation of the face foam prevented us from doing. We allowed 24 hours between tests as specified in the Qualifications Procedures. We tested each dummy until the peak probe force

¹⁶⁶ This is seen in the head impact test series, in which the headskins were found to be repeatable and reproducible, with repeated impacts to the head yielding nearly identical responses.

fell out of the biofidelity corridor (until the peak probe force exceeded 8,200 N). Only those tests which fell within the peak probe force biofidelity corridor were then included in the repeatability analysis and used to set the qualification targets. This gave us eight-to-nine tests for each of the three face foams we tested.

For two of the face foam inserts tested, repeatability CVs were below 10%. The third face foam insert resulted in CVs for peak probe force and peak head CG resultant acceleration of 10.1% and 12.1%. Though not reported in the R&R paper, CVs for the HIC₁₅ values associated with the head resultant accelerations recorded in the face impact test are within 1% of the CVs for peak resultant head CG acceleration. However, in practice, we would likely not observe this level of variability because in several of the tests used to calculate CV, the peak probe force was outside of the qualification targets (either too high or too low) and so the dummy would have been further adjusted before being used in a compliance (or research) test. We observed that when the response of a new face foam insert is too low, it likely indicates the need for an additional “break in” test, in which case the face impact test would be repeated. If the response is too high, it likely indicates that the face foam needs to be replaced, in which case a new face foam insert will be installed and the face impact test repeated. Therefore, we believe that the face impact test is sufficiently repeatable. Moreover, although we did not test at multiple labs to evaluate reproducibility due to face foam degradation, we also believe that the face impact test is reproducible. The head impact test uses essentially the same test apparatus and a similar impact condition as the face impact test. Because the test reproducibility was very good in the head impact test, we expect that there will be acceptable levels of lab-to-lab variability for the face impact test as well.

Neck

For the neck qualification tests, the entire head-neck assembly is removed from the THOR-50M, so the serial numbers listed in Table 9 are those of the individual head-neck assemblies and not the ATD itself.

With respect to repeatability, across all four neck test modes (flexion, extension, lateral flexion, and torsion), CVs for repeatability were below 10% for all qualification test parameters and for all necks, and were below 5% except in the neck flexion test mode for two of the necks: peak upper neck Y-axis

moment (5.8%) and peak upper neck Z-axis force (6.0%) for neck EB6007, and peak upper neck Y-axis moment for neck EB6006 (5.1%). For both of these necks, the first test resulted in a peak upper neck Y-axis moment higher than the resulting qualification targets; thus this first test would have been re-run in practice. If this first test were discarded, the resulting repeatability CVs would be at or below 5% for all necks. Labs may find that while the first neck flexion test performed on a new neck produces a Y-axis moment greater than the qualification targets, subsequent tests result in lower values within the acceptance interval. Also, labs may need to adjust the input pulse by experimenting with honeycomb cell configurations to achieve the target response.

Reproducibility CVs were below 5%, except in four instances, two for the neck flexion test mode, and two for the neck extension test mode.

In the neck flexion test mode, the dummy reproducibility CV for peak upper neck Y-axis moment was 5.4%. This likely results from the same break-in issue described above. Also in the neck flexion test mode, the test reproducibility CV for peak upper neck Z-axis force was 7.5%. In this case, there were two tests each at Calspan and Humanetics that would not have met the resulting qualification specifications,¹⁶⁷ though discarding these tests would still result in a reproducibility CV of 6.4% for peak upper neck Z-axis force. However, we believe that this variance is not likely to lead to inconsistent compliance test outcomes because the average peak upper neck Z-axis force (860 N) represents a very low probability of injury (0.7% risk of AIS 3+ injury). Although NHTSA has not yet established injury assessment reference values (IARVs) for the THOR, when it does (NHTSA anticipates rulemaking in the near future to add the THOR-50M to FMVSS No. 208 as an optional test device) an IARV for neck flexion would almost certainly be specified to correspond to a risk of AIS 3+ injury much higher than 0.7%, *i.e.*, corresponding to a much higher Z-axis force than 860 N.¹⁶⁸

In the neck extension test mode, two test reproducibility CVs were above 5%: peak upper neck Y-axis moment (5.6%) and peak upper neck Z-axis force (12.2%). These elevated CVs result from the tests on neck EB6007 at Calspan, for

¹⁶⁷ R&R Report, Table 6–14.

¹⁶⁸ Upper neck F_z is currently specified in FMVSS NO. 208 as an injury criterion for the HIII-50M and is also a component of THOR-specific N_{ij} criterion.

which the first four tests resulted in peak upper neck Z-axis forces lower in magnitude than the resulting qualification targets, while the last test resulted in a peak upper neck Y-axis moment higher in magnitude than the resulting qualification targets, and at Humanetics, for which four of the five tests resulted in peak upper neck Z-axis forces higher in magnitude than the qualification targets, though by not more than 32 N.¹⁶⁹ However, since all of the remaining tests on neck EB6007 at VRTC (15 tests) would have met the qualification targets, and the associated test reproducibility CVs would be below 3% for all test parameters except for the Calspan observations, this finding likely results from either an issue with test execution at Calspan, or an issue specific to neck EB6007, such as damage or unintended adjustment of the neck spring cables after it was tested at both VRTC and Humanetics.

While the input parameters for the tests conducted on EB6007 were all within the qualification specifications, the pendulum velocity at 20 and 30 milliseconds after T-zero was notably higher at Calspan compared to VRTC and Humanetics, which may explain the differences in results. As such, it may be worth considering narrower specifications on the pendulum velocity input parameters. On the other hand, if the differing results at Calspan resulted from issues with the neck itself, then the fact that the qualification specifications were not met indicates that the qualification tests successfully identified a damaged or improperly configured neck.

Upper Thorax

In the upper thorax qualification test mode, all CVs for repeatability and reproducibility were below 5%, which indicates that the qualification specifications were achievable by three different THOR-50M ATDs and at three different test labs. Further, as all CVs were below 3.7%, this indicates that all tests were within the $\pm 10\%$ target.

Lower Thorax

In the lower thorax qualification test mode, all but one of the CVs for repeatability were below 5%. One repeatability assessment, peak resultant deflection at peak probe force for ATD DO9798, had a CV of 5.2%. For this ATD, peak resultant deflections on the right side were closer to the upper end of the corridor, while those on the left side were closer to the lower end of the corridor. CVs for dummy reproducibility were below 5%. Test

¹⁶⁹ R&R Report, Table 7–16.

reproducibility CVs were slightly above 5%. Here, one of the tests at Humanetics would not have met the resulting peak probe force qualification specifications, while four of the tests at Calspan would not have met the resultant deflection at peak force specification.¹⁷⁰ If the tests that would not fall within the qualification specifications were excluded, as would be done in practice, reproducibility CVs would be below 5%. Overall, the lower thorax qualification specifications were achievable by three different THOR–50M ATDs and at three different test labs.

Abdomen

When the abdomen qualification repeatability and reproducibility testing was conducted, all three THOR–50M ATDs were not available.

As an alternative, three different abdomen assemblies were tested on the same ATD. We believe this modification is acceptable because the abdomen foam inserts and the structure of the abdomen bag are responsible for a majority of the variation in the lower abdomen qualification test, whereas the remainder of the THOR–50M is essentially a ballast.

All of the CVs for repeatability and reproducibility of peak probe force were below 5%. All of the CVs for repeatability and reproducibility of the peak left and right X-axis deflection at the time of peak force were between 5% and 6%. Of these tests, three at Calspan resulted in right abdomen X-axis deflections lower in magnitude than the qualification specifications. While not included in the CV calculation, the difference between left and right X-axis deflection measurement highlighted the fact that all tests at VRTC had a positive difference of at least 6.8 millimeters, indicating that the magnitude of right X-axis deflection was greater than the magnitude of left X-axis deflection in all tests. The opposite was true at Calspan, where three of the tests showed notably higher magnitude deflections on the left side. In total, six of the abdomen qualification tests (five at VRTC and one at Calspan) were beyond the 8 millimeter difference specified by the qualification specifications. Further examination of the test setup at VRTC showed that the ATD was consistently rotated slightly about the Z-axis, resulting in the right side of the abdomen being closer to the probe than the left side, and subsequently recording more deflection. The test configuration at VRTC has since been corrected. This issue is not expected to introduce

variability in test results in the future because such tests outside the qualification targets would necessitate dummy adjustment and re-running the test. If only tests that were within the maximum difference in left-to-right deflection specification were included, both the dummy and test reproducibility CVs would be 5.0% or below.

Upper Leg

As we explained earlier (Section VI, Qualification Tests), the proposed upper leg qualification test procedure reflects revisions to the 2018 Qualification Test Procedures that we made in light of our R&R testing. The CVs for repeatability and reproducibility of the revised test procedure for all three measurements were at or below 5%, demonstrating that the upper leg qualification specifications can be met by three different THOR–50M ATDs at three different test labs.

Knee

For the knee qualification test, all CVs for repeatability were below 5%. For dummy reproducibility, CVs were 5.0% and below for both measures. For test reproducibility, the CV for knee deflection at peak femur Z-axis force was below 5%, while the CV for peak femur Z-axis force was 5.9%. This elevated CV appears to result from the tests at Calspan, which were all generally lower in magnitude than at VRTC and Humanetics, and three of the tests resulted in peak femur Z-axis force lower than the qualification specification. As the three tests that were outside of the qualification specifications were the first or second tests in the series, it is possible that the lower forces resulted from misalignment of the load distribution plate or other slack in the system that was corrected in the remaining tests. In light of this, we believe that the knee qualification repeatability and reproducibility test series demonstrated that the qualification specifications could be achieved by six different THOR–50M knees at three different test labs.

Lower Leg

As used by VRTC, the lower legs are considered modular, and are typically assigned to a THOR–50M on deployment and not necessarily tied to a specific THOR–50Ms serial number. As such, the repeatability and reproducibility qualification study was carried out by testing three different lower legs at VRTC, followed by testing two of those legs at both Humanetics and Calspan. This resulted in a total of 15 tests for the dummy reproducibility

assessment, and 30 tests for the reproducibility assessment (although several of the tests at Calspan were not included because they did not meet the test velocity input specifications).

For all the lower leg test modes, repeatability CVs were all below 5%, indicating that the qualification specifications are achievable by three different THOR–50M ATDs. There were, however, a few test mode/parameters for which reproducibility CVs were above 5%.

In the ankle inversion test mode, test reproducibility for the peak lower tibia Z-axis force measurement was 5.3%. The source of this elevated CV appears to be the first test of leg DL5405 at VRTC, where the peak lower tibia Z-axis force was –451 N, which was just outside the acceptance interval (–454 to –555 N). In practice, this test would have been re-run, and all the remaining tests on this leg would have met the qualification targets. Removing this test from the CV calculation would result in a test reproducibility CV of 4.9%.

In the ankle eversion test mode, dummy reproducibility was above 5% for the peak lower tibia Z-axis force (5.7%), and test reproducibility was above 5% for lower tibia Z-axis force (6.0%) and peak ankle resistive moment (5.1%). These elevated CVs appear to result from the first tests on DL0202 at VRTC, where the peak lower tibia Z-axis force (–512 N) was just outside the acceptance interval (–514 N to –629 N), and at Calspan, where the peak lower tibia Z-axis force (–454 N) and the peak angle resistive moment (35.6 Nm) were both below the lower end of the associated qualification specifications (–514 N and 38.7 Nm, respectively). In practice, these tests would have been re-run, and all the remaining tests on this leg at both labs would have met the qualification specification. Removing these two tests from the CV calculation would result in reproducibility CVs all below 5%, which demonstrates that the ankle eversion qualification specifications can be met by six different legs at three different test labs.

In the ball-of-foot test mode, which assesses both the impact response of the ball-of-foot portion of the molded shoe and the dorsiflexion response of the ankle, the only CV above 5% was the test reproducibility of the peak ankle resistive moment (6.9%). In the tests at Calspan, only two of the five tests on the left leg (DL0202) met the qualification specification for input velocity. The three tests that did not meet the qualification specification were considered invalid tests and therefore were not included in the test

¹⁷⁰ R&R Report, Table 11–9.

reproducibility assessment, so only seven tests from Calspan were included as opposed to 10 tests from each of the other labs. Of the tests run by Calspan on the right leg (DL5404), four of the five resulted in peak ankle resistive moments of 61.3 to 61.8 Nm, just above the upper end of the qualification specification (60.8 Nm). As the tests at

Calspan were consistently higher in peak ankle resistive moment than those at VRTC and Humanetics, it is possible that this finding results from either an issue with test execution at Calspan, or an issue specific to leg DL5404, such as damage or unintended adjustment of the Achilles spring cables after it was tested at both VRTC and Humanetics.

Reviewing the time-history data for ankle resistive moment from exemplar tests from Calspan, VRTC, and Humanetics (Figure 1), there are some differences early in the event (note the large positive moment before 10 milliseconds in the Calspan test) that suggest differences in test setup and/or impactor hardware.

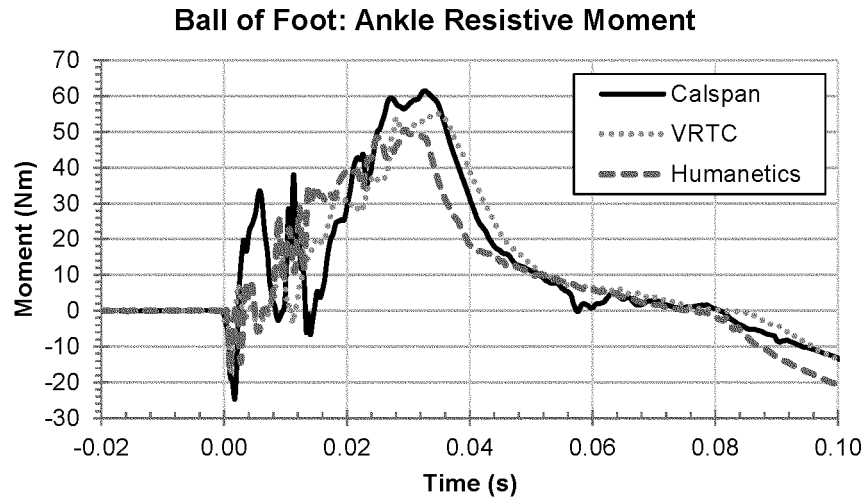


Figure 1. Ankle resistive moment in the ball-of-foot impact test, showing exemplar tests from Calspan (b12293), VRTC (b12541), and Humanetics (b12405).

In the heel impact test, which assesses both the impact response of the heel portion of the molded shoe and the tibia compliant element, the repeatability CVs were all under 5%, but both the dummy (6.4%) and test (5.9%) reproducibility CVs were over 5%. If the test CVs are calculated independently for the left and right legs, the resulting CVs are much lower (2.1% and 3.0%, respectively). This suggests that the test itself is repeatable (as all repeatability CVs were 1.6% or below) and reproducible, but that there is some ATD-to-ATD (in this case, leg-to-leg) variation. Nonetheless, the qualification specifications for the heel impact test can be met using three different legs in at least two different test labs.

Additional Qualification Test Lab

We performed a variety of vehicle tests (discussed in Section VIII, Overall Usability and Performance) where multiple dummies were qualified at two different labs, including a lab (Applus+ IDIADA KARCO Engineering LLC) that was not one of the laboratories used to develop the qualification specifications, and it was possible to qualify the dummies. This qualitative information

gives us further confidence that the qualification tests are reproducible. Therefore, NHTSA tentatively concludes that there is a sufficiently high degree of uniformity in the construction of the dummy components being tested and in the procedures followed by the labs for that test requirement for the THOR-50M to be incorporated into Part 572.

B. Sled Tests

THOR-50M repeatability was also assessed through sled tests representing several different vehicle crash environments, including unbelted, standard, and load-limited three-point belt configurations at different speeds for both the driver and right front passenger seating positions, as well as several restraint configurations in the rear seat. NHTSA's sled test repeatability analysis is based on data from three different sled test series that NHTSA ran in the course of developing THOR-50M. One is a sled test series conducted to develop thoracic injury criteria for the THOR-50M. Another is a sled test series conducted to assess the performance of THOR-50M in low-speed belted crashes. The third is a sled

test series conducted to assess THOR-50M's performance in low-speed unbelted crashes.

In summary, while there were several cases where the variation from test to test of the same THOR-50M ATD was greater than 10%, these cases can be explained by either differences in physical interactions (e.g., contact of the head with the arm in the rear seat sled test), which can be addressed by careful pre-test positioning of the ATD, or by the low magnitude of the measurements, as demonstrated through the use of normalized CV to identify cases where the variation occurs at a much lower level than would be associated with a risk of injury.

This is discussed in more detail in the sections that follow. We begin by explaining our methodology, and then proceed to discuss the three different test series.

1. Methodology

As with the qualification R&R analysis, we assessed repeatability using the coefficient of variation. The CVs were calculated for each of the injury criteria described in the THOR-50M injury criteria report, as well as for peak

values from a few other key data channels:¹⁷¹ lap belt, upper shoulder belt, and lower shoulder belt.

The CV analysis was the same as in the qualification test R&R study, with two modifications. As with the qualification test R&R study, CVs below 5% were considered to require no further investigation; for CVs between 5% and 10% we reviewed the results for outliers; and for CVs greater than 10% we thoroughly investigated the sources of variability in the test procedure and the ATD. However, our assessment differed in two ways from the CV assessment in the qualification R&R study.

First, we used the population standard deviation instead of the sample standard deviation to calculate the CV because these test series are the only sled test series that have been run.¹⁷² Accordingly,

$$CV = \frac{\sigma}{\mu} \times 100\%$$

$$\sigma = \sqrt{\frac{\sum(x_i - \mu)^2}{N}}$$

Second, in addition to the CVs we also considered the normalized CVs. A potential limitation of the CV calculation is that when the magnitude of a given measurement is relatively low, as is the case with off-axis sensor channels, the standard deviation can be high relative to the mean, leading to CVs over 10%. However, this result is not necessarily meaningful: although the amount of variation might be high relative to the mean, it might not be high with respect to say, a critical value of the measurement being evaluated (e.g., in the context of a compliance test involving an ATD, it might not be high with respect to the IARV). This was generally not an issue in the qualification test R&R analysis because the qualification modes, test parameters, and targets were all selected because they are meaningful to the test mode and/or are in the primary load path, so that the resulting measurements were generally of sufficient magnitude for a reliable CV calculation. In sled and vehicle crash tests, on the other hand, it is not known in advance which sensor channels will be of sufficient magnitude for a reliable CV assessment. For this reason, researchers often disregard high CV values when the magnitude of the measurement is relatively low.

However, determining the level of the measurement below which CV is not reliable is inherently subjective.

Accordingly, for CVs above 10% we also considered normalized CVs. To calculate normalized CV, the mean (μ) in the CV calculation (Eqn. 1) is replaced with a meaningful, pre-determined reference value. Such a reference value could be an IARV or a measurement value that corresponds to an injury risk similar to the risk that would correspond to an IARV. Because IARVs for the THOR-50M have not yet been finalized, in most cases we calculated the normalized CV using the value associated with a 50% risk of AIS 3+ (above the pelvis) or AIS 2+ (below the pelvis) injury as the reference value.¹⁷³ However, there is not a known risk function that relates belt forces to risk of injury, so for this metric we normalized using the average shoulder belt force from the thoracic injury criteria development data set, for which just over 50% of the subjects sustained AIS 3+ thoracic injuries (a denominator of 5,000 N).¹⁷⁴ The normalization denominators used for each of the measurements are shown in Table 12.

TABLE 12—NORMALIZATION DENOMINATORS FOR CALCULATION OF NORMALIZED CV

Metric	Normalization factor	Normalization rationale
HIC15	1724	50% risk of AIS 3+ injury.
Bric	0.96.	
Neck Tension	4,662 N	50% risk of AIS 3+ injury when used in Nij risk function.
Neck Compression	-5,017 N.	
Nij	1.11	50% risk of AIS 3+ injury.
Chest Peak Res. Defl.	51.4 mm.	
Left Femur Axial Force	10,577 N	50% risk of AIS 2+ injury.
Right Femur Axial Force	10,577 N.	
Peak Femur Axial Force	10,577 N.	
Lap Belt Force	5,000 N	Average from thoracic injury criteria development data set.
Upper Shoulder Belt Force	5,000 N.	
Lower Shoulder Belt Force	5,000 N.	

As an example, consider a repeated test with peak femur forces of 500 N, 1,000 N, and 1,500 N. For these tests, the calculated CV would be 41% (standard deviation of 408 N divided by average of 1000 N), which would require a thorough investigation of the test procedure and ATD. However, these femur forces are all well below 10,577 N, the force at which 50% risk of AIS 2+ injury occurs. Thus, calculating a

normalized CV may provide a more meaningful assessment. In this case, the normalized CV would be 4% (standard deviation of 408 N divided by 50% risk of AIS 2+ injury of 10,577 N), which would require no further investigation.

2. Thoracic Injury Criteria Development Sled Tests

One source of data NHTSA looked at to further assess repeatability is a sled

test series conducted to develop thoracic injury criteria for the THOR-50M. This involved conducting matched-pair tests of PMHS and a THOR-50M ATD in a variety of sled

¹⁷¹ The low-speed sled tests have fewer metrics than the thoracic injury criteria set (11 vs. 12) because lower shoulder belt loads were not recorded in the low-speed sled tests.

¹⁷² This differs from the qualification tests, for which it is known that the data set is a sample of

a larger population (because NHTSA and other test labs have run the qualification tests on other THOR-50M ATDs).

¹⁷³ Fifty percent risk of a given injury severity is a widely-used tolerance level in ATD research.

IARVs specified in the FMVSS may or may not correspond to a 50% risk.

¹⁷⁴ We used the shoulder belt force to normalize the lap belt force because there was not meaningful lap belt force data in some of the thoracic injury criteria development test conditions.

test conditions.¹⁷⁵ This series tested the same THOR–50M unit in three to four repeat tests in each of six different test conditions: Gold Standard 1, 2, and 3; Rear Standard; Rear Load-limited (Rear LL); and Rear Inflatable (Table 13).¹⁷⁶

TABLE 13—THOR–50M THORACIC INJURY CRITERIA DEVELOPMENT TEST MATRIX

TSTNO	TSTREF	Nominal test speed (km/h)	Test condition name, description
11117	S0156	40	<i>Gold Standard 1</i> : flat rigid seat, standard lap and shoulder belts, knees restrained, right front passenger restraint geometry.
11118	S0157		
11119	S0158		
11120	S0159	30	<i>Gold Standard 2</i> : flat rigid seat, force-limited shoulder belt and standard lap belt, knees restrained, right front passenger restraint geometry..
11121	S0160		
11122	S0161		
11514	UVAS0309	30	<i>Gold Standard 3</i> : flat rigid seat angled 30 degrees counterclockwise, force-limited shoulder belt and standard lap belt, knees restrained, right front passenger restraint geometry.
11515	UVAS0310		
11516	UVAS0311		
11517	UVAS0312		
11143	S0199	48	<i>Rear Standard</i> : rear passenger in 2004 Ford Taurus buck; 3-point standard belt.
11144	S0200		
11145	S0201		
11140	S0196	48	<i>Rear LL</i> : rear passenger in 2004 Ford Taurus buck; 3-point load-limited belt with pretensioner.
11141	S0197		
11142	S0198		
11137	S0193	48	<i>Rear Inflatable</i> : rear passenger in 2004 Ford Taurus buck; 3-point inflatable force-limited belt with pretensioner.
11138	S0194		
11139	S0195		

Notes: All tests were on THOR–50M S/N 9207. These tests are available in the NHTSA biomechanics database.

We calculated CVs and normalized CVs for each of the injury criteria described in the THOR–50M injury criteria report, as well as a few other key

data channels, for a total of 12 metrics for each of the six test conditions. See Table 14 (CVs) and Table 12 (normalization denominators). Sixty-

five of the seventy-two CVs calculated were below 10%, while seven CVs were 10% or above.

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¹⁷⁵ Craig, M., Parent, D., Lee, E., Rudd, R., Takhounts, E., Hasiija, V. (2020). Injury Criteria for the THOR 50th Male ATD. Docket ID NHTSA–2019–0106–0008, available at: <https://www.regulations.gov/document/NHTSA-2019-0106-0008>.

¹⁷⁶ Our testing included a seventh test condition: Far-Side Oblique (representing the right front passenger in an oblique moving deformable barrier crash test). The THOR–50M setup and positioning, however, differed in each of these tests. These tests were not valid for the purposes of the repeatability

analysis, because the differences in setup and positioning is expected to—and in fact did—lead to a wider variation in results. Specifically, the CVs for 8 of the 15 measurements exceeded 10%, with most of these over 20%, and some as high as 72%.

Table 14. Coefficients of Variation for the thoracic injury criteria development data set.

Coefficient of Variation (CV), Percent (%)	HIC15	BrIC	Neck Tension	Neck Compression	Nij	Chest Peak Res. Defl.	Femur Left Force	Femur Right Force	Femur Peak Force	Lap Belt Force	Upper Sh. Belt Force	Lower Sh. Belt Force
Gold Standard 1	3.3 [0.4]	7.5 [8.0]	3.6 [1.6]	10.8 [0.8]	10.0 [6.4]	0.5 [0.5]	2.6 [1.0]	1.4 [0.5]	2.6 [1.0]	12.5 [1.0]	0.3 [0.5]	5.1 [4.0]
Gold Standard 2	4.4 [0.1]	4.9 [3.1]	3.8 [0.8]	8.3 [0.5]	2.0 [0.5]	1.5 [0.8]	9.3 [1.9]	2.2 [0.5]	2.2 [0.5]	6.0 [0.4]	0.2 [0.1]	7.1 [2.6]
Gold Standard 3	7.3 [0.2]	1.8 [1.1]	5.2 [1.2]	7.3 [0.2]	5.1 [1.6]	3.1 [2.2]	8.2 [1.1]	3.4 [1.0]	3.4 [1.0]	6.7 [0.3]	1.5 [0.9]	2.7 [2.0]
Rear Standard	9.9 [3.3]	1.2 [1.2]	13.7 [0.4]	2.9 [1.8]	2.8 [1.7]	1.3 [1.4]	N/A	N/A	N/A	5.2 [7.4]	2.0 [2.8]	3.9 [4.2]
Rear LL & pretensioned	4.0 [0.9]	10.9 [9.6]	5.1 [2.7]	23.3 [3.4]	3.8 [2.4]	5.0 [4.5]	N/A	N/A	N/A	6.3 [8.7]	1.4 [1.6]	8.0 [8.3]
Rear Inflatable	20.5 [2.0]	3.9 [2.4]	2.0 [0.7]	7.4 [1.5]	2.4 [1.1]	7.4 [4.3]	N/A	N/A	N/A	8.7 [11.7]	3.9 [2.3]	N/A

[] = normalized CV

Shaded cells = $CV \geq 10\%$ and normalized CV < 10%

Shaded & italicized = $CV < 10\%$ and normalized CV $\geq 10\%$

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We believe that this data supports our tentative conclusion that the THOR-50M is sufficiently objective for inclusion in Part 572. Almost all the CVs were below 10%, and many were at or below 5%. For the seven CVs at or above 10%, we believe that these do not indicate that the dummy does not yield repeatable results. These seven measurements with CVs above 10% were: Gold Standard 1 condition for neck compression, Nij, and lap belt

load; rear-seat standard belt condition neck tension; rear-seat load-limited condition for BrIC and neck compression; and rear-seat inflatable belt condition for HIC₁₅). When normalized, however, none of these CVs were above 10%. This suggests that the variability in these measurements would not likely lead to variability in actual testing outcomes. The variability in these measurements is much lower than the magnitudes of these

measurements that would be used as an IARV specified in FMVSS No. 208.

For instance, the individual measurements for neck compression in the Gold Standard 1 tests were -394 N, -427 N, and -328 N. These have an average of -383 N and a standard deviation of 41 N, resulting in an unadjusted CV of 11%. While this is greater than 10%—potentially suggesting that the source of this variability needs investigation—these measurements are all much lower in

magnitude than the compression force that would result in a 50% risk of AIS 3+ injury (– 5017 N). When the standard deviation is compared to this compression force instead of the average neck compression, we obtain a normalized CV of 0.8%. This suggests that the magnitudes of the neck compression measurements are low compared to the magnitude of compression that corresponds to a meaningful injury risk.

There was one measurement for which the unadjusted CV was below 10% but the normalized CV was above 10%: the peak lap belt force in the rear-seat inflatable belt condition, which had a normalized CV of 11.7%. In this instance, the average lap belt load (6,701 N) was higher than the normalizing denominator (5,000 N), resulting in an inflated normalized CV. As stated earlier, there is not a known risk function that relates belt forces to risk of injury, so this elevated normalized CV is not of particular concern.

Otherwise, the highest normalized CV occurred in the BrIC measurement in the rear seat load-limited and pretensioned condition (9.6%). This appears to result from inconsistent initial positioning of the left arm, which

is more of a test procedure concern than a THOR–50M concern.

3. Low-Speed Belted Sled Tests

Another source of data NHTSA looked at to assess repeatability is a sled test series conducted to assess the performance of THOR–50M in low-speed belted conditions. These tests were based on the rigid barrier, perpendicular impact belted crash test specified in FMVSS No. 208 for the HIII–50M. Sled tests were conducted at crash pulses representing three frontal rigid barrier impact velocities (24, 32, and 40 km/h) (15, 20, and 25 mph). This range of speeds was selected because FMVSS No. 208 specifies a speed of up to 56 km/h (35 mph) for this crash test, and air bag deployment thresholds are typically around 24 km/h (15 mph); we spanned the 24–40 km/h (15–25 mph) range and selected a mid-point of 32 km/h (20 mph) to conduct a crash test and get a crash pulse. In each test, the THOR–50M was seated in either the driver or right front passenger seating locations of a buck representing a mid-sized passenger car.¹⁷⁷ Three tests were conducted at each impact velocity, for a total of 9 tests. The test buck was

¹⁷⁷ A HIII–50M was seated in the other front outboard seat.

created from an actual vehicle, and included seat belts, front air bags, knee-bolsters, and pretensioners. The test matrix and additional information about the test setup is provided in Appendix D.

As with the thoracic injury criteria development test series, both CVs and normalized CVs (Table 15) were calculated for each of the relevant injury metrics described in the THOR–50M Injury Criteria Report, as well as femur and seat belt loads, for 11 metrics for each of the six test conditions. Of these 66 CVs, 31 were under 5%, 17 were between 5% and 10%, and 18 were above 10%.

We believe that this data supports our tentative conclusion that THOR–50M is sufficiently objective to include in Part 572. Most of the CVs were under 10% and many were under 5%. None of the 18 measurements for which the CV was above 10% had a normalized CV over 10%, and only five were above 5%. This is not surprising, as the low-speed belted test condition presents a low likelihood of injury. Thus, while there may be variations in the injury metrics, these variations are small relative to the values that would represent a meaningful injury risk.

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Table 15. Coefficient of Variation for the low-speed frontal sled test data set.

Coefficient of Variation (CV), Percent (%)	HIC15	BrIC	Neck Tension	Neck Compression	Nij	Chest Peak Res. Defl.	Femur Left Force	Femur Right Force	Femur Peak Force	Lap Belt Force	Shoulder Belt Force
Driver, 24 km/h	7.7 [0.3]	3.1 [2.4]	5.5 [1.5]	18.4 [0.8]	6.6 [2.4]	1.1 [1.0]	13.7 [3.6]	15.2 [4.1]	7.7 [2.2]	3.7 [1.5]	3.5 [4.3]
Driver, 32 km/h	3.8 [0.3]	1.6 [1.1]	7.0 [2.2]	9.8 [0.4]	3.8 [1.6]	5.2 [4.1]	16.4 [1.9]	15.0 [2.5]	15.0 [2.5]	9.97 [6.5]	4.6 [3.0]
Driver, 40 km/h	3.1 [0.6]	3.2 [2.3]	3.3 [1.4]	17.2 [0.6]	1.9 [1.0]	1.6 [1.3]	33.0 [5.8]	21.6 [7.0]	21.6 [7.0]	5.6 [5.9]	4.6 [3.5]
RFP, 24 km/h	15.9 [0.5]	3.6 [2.6]	6.3 [1.6]	31.6 [1.3]	5.9 [2.2]	2.4 [2.1]	7.7 [2.2]	8.2 [3.4]	8.2 [3.4]	4.1 [1.6]	2.4 [3.5]
RFP, 32 km/h	9.9 [0.4]	2.8 [1.7]	6.4 [1.4]	24.2 [1.0]	4.7 [1.3]	2.3 [1.4]	21.0 [3.6]	6.3 [1.2]	10.8 [2.1]	2.7 [1.5]	1.2 [0.8]
RFP, 40 km/h	10.2 [1.0]	2.0 [1.4]	6.6 [1.6]	18.9 [0.9]	3.0 [0.9]	1.2 [0.8]	12.9 [3.6]	3.3 [1.1]	3.3 [1.1]	3.2 [3.1]	3.5 [2.5]

[] = normalized CV

Shaded cells = CV \geq 10% and normalized CV < 10%

4. Low-Speed Unbelted Sled Tests

Another source of data NHTSA looked at to assess repeatability is a sled test series conducted to assess the performance of THOR-50M in a low-speed unbelted condition. Sled tests

were conducted at crash pulses representing two frontal rigid barrier impact velocities, 32 km/h (20 mph) and 40 km/h (25 mph), with the THOR-50M in both the driver and right front passenger seating locations of a test buck. Three tests were conducted at

each impact velocity. The test buck was identical to that used in the low-speed belted tests except for some minor modifications. The test matrix and additional information about the test setup is provided in Appendix E.

Table 16. Coefficient of Variation for the unbelted frontal sled test data set.

Coefficient of Variation (CV), Percent (%)	HIC15	BrIC	Neck Tension	Neck Compression	Nij	Chest Peak Res. Defl.	Femur Left Force	Femur Right Force	Femur Peak Force
Driver, 32 km/h	7.7 [1.5]	7.6 [5.5]	39.0 [2.8]	7.9 [5.8]	5.3 [5.6]	2.6 [2.1]	4.9 [2.3]	6.4 [3.2]	5.1 [2.6]
Driver, 40 km/h	9.6 [2.0]	16.7 [14]	8.7 [0.8]	8.8 [8.3]	<i>4.7</i> [10.7]	6.0 [5.2]	6.4 [3.5]	9.2 [7.3]	9.2 [7.3]
RFP, 32 km/h	8.6 [1.6]	5.7 [5.1]	5.3 [0.4]	3.3 [3.8]	2.1 [3.5]	4.0 [1.9]	2.7 [1.7]	4.1 [2.6]	2.6 [1.7]
RFP, 40 km/h	13.1 [2.7]	2.9 [2.0]	10.9 [1.0]	9.2 [5.8]	5.3 [9.9]	9.9 [7.7]	7.1 [5.1]	1.1 [0.8]	2.6 [2.0]

[] = normalized CV

Shaded cells = CV ≥ 10% and normalized CV < 10%

Shaded & italicized = CV < 10% and normalized CV ≥ 10%

Shaded & Bold = CV > 10% and normalized CV > 10%

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As with the thoracic injury criteria development and belted test series, CVs and normalized CVs were calculated for each of the relevant injury metrics described in the THOR-50M Injury Criteria Report, as well as femur loads, for nine metrics for each of the two crash pulses. Of these 36 CVs, 12 were less than 5%, 20 were between 5% and 10%, and four were above 10% (Table 16).

We believe this supports our tentative conclusion that the THOR-50M is objective. Almost all the CVs were under 10%, and many were under 5%. Three of the four measurements with a CV over 10% had a normalized CV under 10% (neck tension for driver 32 km/h and RFP 40km/h, and HIC₁₅ for RFP 40 km/h), suggesting that the variation is small relative to the values

that would represent a meaningful injury risk. The low magnitudes of neck tension occur because there is no torso restraint in these unbelted tests, so that the tension force acting on the neck due to the deceleration of the torso is minimal (below 500 N). The HIC₁₅ measurements were relatively low because the frontal air bags minimized the contact of the head with hard surfaces or at least decelerated the head before contact. The highest average HIC₁₅ (360) occurred in the right front passenger 40 km/h condition, where individual measurements of 309, 349, and 423 resulted in a standard deviation of 47.3 and a CV of 13.1.

Only one of those four measurements that had a CV over 10% also had a normalized CV over 10% (BrIC in the Driver 40 km/h condition, 14%).

NHTSA's analysis of the test procedure and ATD revealed that the variation in this case appears to result from a difference in head interaction with the sun visor and underlying roof structure, brought about by small differences in the timing and/or position of the head at the time of contact. This variation could be brought on by initial position differences, differences in interaction of the pelvis and thighs with the seat cushion during initial forward translation, or differences in knee interaction with the knee bolster and/or knee bolster air bag. For additional information on this analysis, see Appendix E.

There was one measurement with a relatively low CV, but an associated normalized CV above 10%. This occurred for the Nij measurement in the

driver 40 km/h condition, where the CV was 4.7% and the normalized CV was 10.7%. Because we normalized by the value of N_{ij} associated with a 50% injury risk, this indicates that the average value of N_{ij} from the three tests in the driver 40 km/h condition were above an N_{ij} associated with 50% risk of injury. Closer inspection of the data revealed several peaks that cannot be explained by the interaction of the dummy with the restraint system and vehicle interior. This suggests possible damage to a load cell or cabling. For additional information on this analysis, see Appendix E.

VII. Overall Usability and Performance

NHTSA’s extensive testing with the THOR–50M has also enabled it to assess THOR–50M’s overall usability and performance. This includes durability, ease and frequency of maintenance, and how the ATD fits and responds in the vehicle environment. We discuss these issues in the sections that follow.

A. Assembly and Qualification

Based on NHTSA’s experience with the dummy at VRTC, assembling the THOR–50M following the instructions in the PADI takes roughly 80 hours, as detailed in Table 17.

We note that NHTSA treats its THOR–50M units not so much as a serialized dummy, but as a set of serialized parts and sub-assemblies. NHTSA’s THOR–50M units typically undergo a routine breakdown and inspection after each application; when the dummy is reassembled, different parts may be introduced (for example, if a part needed to be refurbished before it could be used again). In addition, parts or sub-

assemblies may be taken out of service at regular intervals and set aside to await preventative maintenance. For example, a head and neck sub-assembly (both of which are serialized) may be taken out of service at regular intervals and set aside to await preventative maintenance; once clear, the head and neck sub-assembly may end up in another serialized dummy. Therefore, a serialized dummy does not typically define the dummy well because different parts are constantly being interchanged. The parts and assemblies which are serialized, either by the manufacturer or by NHTSA upon delivery of a new ATD or part, are listed in Appendix C.

TABLE 17—ESTIMATED TIME TO CARRY OUT ASSEMBLY AND ASSOCIATED PROCEDURES DESCRIBED IN THE THOR–50M PADI

PADI assembly time	
Body region or procedure	Time (hrs)
Head	4
Neck	8
Spine	4
Thorax	8
Shoulder	4
Upper Abdomen	4
Lower Abdomen	4
Pelvis	8
Upper Leg	4
Lower Extremity	8
Arm	4
Jacket and Clothing	4
Bundling Cables	4
Polarity Check	4
Documentation	8
Total	80

Based on NHTSA’s experience at VRTC, a complete qualification test series of 24 tests takes roughly 80 hours, assuming that the qualification specifications are met (Table 18). If the qualification specifications are not met, it may take additional time to inspect, replace parts where necessary, and re-test. Table 19 describes the equipment required to carry out the THOR–50M qualification tests, along with the associated setup procedures. Some of this equipment is the same or similar to the equipment required for qualification of ATDs currently defined in Part 572. For example, the THOR–50M qualification procedures for the neck and the upper thorax use the same equipment as used in qualification of the HIII–50M. For equipment not currently defined in Part 572, the necessary drawings are included in the THOR–50M drawing package with two exceptions: the impactors for the face qualification test and upper leg and knee qualification tests. We believe that existing impactors (such as the knee impact probe for the HIII–5F¹⁷⁸) can be modified or ballasted to achieve the required mass.

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¹⁷⁸ 49 CFR 572.137(b).

Table 18. Estimated time to conduct qualification tests.

Qualification Testing Time			
Test		Time (Hrs)	
Component Tests	A	Neck Torsion	5
		Neck Flexion	5
		Neck Extension	5
		Neck Lateral	5
	B	Knee	4
	C	Ankle Inversion	4
		Ankle Eversion	4
		Ball of Foot	4
		Heel	4
	Full Body Tests	Face	4
Head		4	
Upper Thorax		8	
Lower Thorax		8	
Abdomen		8	
Upper Leg		8	
Total		80	

TABLE 19—EQUIPMENT REQUIRED FOR QUALIFICATION TESTS

Test fixture description [±0.02 kg, ±0.25 mm]	Reference	Section(s)	Title
Rigid disk impactor 23.36 kg, 152.4 mm diameter disk.	CFR Title 49, § 572.36(a); DL500–325	4, 7, 8	Head, Upper Thorax, Lower Thorax.
Rigid disk impactor 13.0 kg, 152.4 mm diameter disk.	THOR–50M Qualification Procedures, Section 5.2.	5	Face.
Neck pendulum	Figure A–2; CFR Title 49, § 572.33(c)3	6.6, 6.7, 6.8, 6.9	Neck Torsion, Neck Frontal Flexion, Neck Extension, Neck Lateral Flexion.
THOR neck twist fixture	DL472–1000	6.6	Neck Torsion.
Lower abdomen probe face assembly ...	DL472–3000	9	Abdomen.
Rigid disk impactor 12.0 kg, 76.2 mm diameter disk.	THOR–50M Qualification Procedures, Section 11.2.	11	Upper Leg, Knee.
Dynamic impactor	TLX–9000–013	12, 13, 14	Ankle Inversion and Eversion, Ball of Foot, Heel.
External positioning bracket	TLX–9000–016M	12, 14	Ankle Inversion and Eversion, Heel.
Dynamic inversion/eversion bracket	TLX–9000–015	12	Ankle Inversion and Eversion.
Lower leg mounting bracket assembly ..	DL472–4100	12, 13	Ankle Inversion and Eversion, Ball of Foot
Lower leg zero bracket	DL472–3500	3.4	Ankle Rotary Potentiometer Zeroing Procedure.
Achilles fixture complete assembly	DL472–4000	3.5	Achilles Cable Adjustment Procedure.
Load cell mounting assembly	DL472–4200	3.5	Achilles Cable Adjustment Procedure.
Knee slider load distribution bracket assembly.	DL472–5000	11	Knee.
Tibia adaptor	DL472–4300	14	Heel.

B. Durability and Maintenance

In previous sections of the NPRM, we have discussed NHTSA’s biofidelity testing, qualification testing, and sled tests. In this testing, we generally observed that THOR–50M stood up well during testing and required maintenance consistent with existing Part 572 ATDs. In addition to that testing, NHTSA has conducted a variety of other tests over the last several years as development of THOR–50M has progressed. With respect to evaluating THOR’s durability and maintenance needs, three series of tests are especially useful because they subject the THOR–50M to more severe or challenging crashes: elevated energy qualification tests; OMDB testing; and unbelted FMVSS No. 208 tests. We discuss this testing in the sections that follow.

1. Elevated Energy Qualification Test Series

In order to assess THOR–50M’s durability, NHTSA conducted an additional series of qualification tests at elevated energy levels (for example, impactor velocities that exceeded the levels specified in the qualification test procedures).¹⁷⁹ A series of five tests was conducted for each of the qualification test modes (except, as explained below, the abdomen). The first test in each set

was a baseline test performed according to the qualification, except that if the response measurement did not either represent at least a 50% risk of injury or have a magnitude greater than the mean plus one standard deviation of the same measurement in a set of 18 oblique vehicle crash tests,¹⁸⁰ the test speed was increased until either of those targets were met; this was then considered the baseline speed. There were two test modes where the test speed specified in the qualification procedures did not reach either of these targets: upper leg impact and heel impact.¹⁸¹ The next three tests were at speeds corresponding to energy level increases of 10 percent, 20 percent, and 30 percent. A final baseline test was then performed at the prescribed qualification test velocity. The results were considered to show acceptable durability if the final baseline test demonstrated a response similar to the initial baseline test and within the qualification targets, and visual inspection revealed no damage to any of the dummy components. For a majority of the qualification test modes, durability was found to be acceptable.

¹⁸⁰ Saunders, J., Parent, D., Ames, E., 2015. NHTSA oblique crash test results: vehicle performance and occupant injury risk assessment in vehicles with small overlap countermeasures. In: Proceedings of the 24th International Technical Conference for the Enhanced Safety of Vehicles (No. 15–0108). Available at https://downloads.regulations.gov/NHTSA-2019-0106-0008/attachment_1.pdf.

¹⁸¹ The increase in energy of the upper leg impact test was later implemented in the revised qualification procedure.

No visible damage was observed in any of the tested components after the series of five tests. Two exceptions to these findings occurred in the face and the abdomen qualification test modes.

In the face impact test, the final baseline peak probe force and peak head CG resultant acceleration were higher than the qualification specifications. This is consistent with the results of the qualification R&R study (Section VI.A). While not ideal, we believe that, because this is now a known issue, it can be managed with the replacement of a face foam insert when the face qualification test results are higher in magnitude than the qualification specification. Moreover, the deterioration in the face foam insert probably would not meaningfully affect crash test results because, in a vehicle test, more energy will likely be absorbed by a vehicle interior component and/or restraint system compared to the rigid qualification impact probe. However, NHTSA would consider specifying a different face foam material or design that had improved durability, as long as the material or design does not introduce unintended consequences such as negatively impacting biofidelity, changes to the inertial properties of the head, degradation of repeatability and reproducibility, overall usability, or other concerns.

We did not conduct elevated-energy tests for the abdomen because the qualification test already demonstrates a higher energy condition than a vehicle crash test. Accordingly, impacts at a

¹⁷⁹ National Highway Traffic Safety Administration (2020). THOR–50M Durability Report. *Regulations.gov* Docket ID NHTSA–2019–0106–0003, available at: <https://www.regulations.gov/document/NHTSA-2019-0106-0003>.

higher energy level could cause damage due to exhausting the stroke of the abdomen instrumentation. Moreover, this would not be meaningful as it would represent a loading condition not representative of the front seat vehicle crash test environment. However, we do recognize that our testing has shown that damage to the abdomen deflection instrumentation can occur in vehicle crash test environments where submarining is possible, such as reclined rear seats. For example, several rear seat sled tests were conducted at VRTC in 2015 in which the IR-TRACCs installed in the abdomen experienced dislodged internal retaining rings and damage including pinched cables. These issues are believed to have resulted from interaction of the IR-TRACC tubes with the foam inserts inside of the lower abdomen bag. To address this, the lower abdomen sewing assembly (472-4763) was redesigned in late 2015, and an inspection procedure was added to the drawing package (472-8320) to ensure that the lower abdomen foam inserts remain aligned once installed in the assembled lower abdomen bag.

We seek comment on these issues, especially on alternative equivalent face foams.

2. Oblique OMDB Test Series

In developing THOR-50M, NHTSA ran a series of full-vehicle oblique tests with a moving deformable test barrier (OMDB).¹⁸² Three crash tests were conducted on the same make/model vehicle (a 2016 Mazda CX-5) at three different test facilities. ATDs were seated in both front outboard seats and were fully qualified. Two THOR-50M ATDs were successfully implemented in

¹⁸² Saunders, J., & Parent, D. (2018). Repeatability and reproducibility of oblique moving deformable barrier test procedure (No. 2018-01-1055). SAE Technical Paper, available at <https://www.regulations.gov/document/NHTSA-2019-0106-0005>. The discussion here briefly summarizes some of the relevant results from this report. This testing is not being considered as an evaluation of the ATD's repeatability and reproducibility because in order to provide a meaningful ATD R&R analysis, control of the test conditions must be exercised. Component tests, such as the qualification tests, are more readily controlled and thus may be expected to provide the best estimates of a dummy's R&R. Sled testing provides an efficient alternative to vehicle crash testing and offers insight into the dummy's performance as a complete system. In full-vehicle crash testing, however, the variation contributed by the vehicle (e.g., variation in structural materials) and the overall test procedure make it difficult to identify the variability attributable to the dummy itself. Additionally, the severity of the test conditions utilized for R&R assessment must also be considered. For example, if the test conditions are so severe that the responses are near or beyond the dummy's mechanical limits or electronic capacity, then the corresponding R&R analysis may not be meaningful. See generally Rhule et al (2005).

a total of nine vehicle crash tests, with qualification tests before and after each set of three tests. In this test condition, there were no signs of damage beyond normal wear and tear, and there were no sensor failures that were critical to the calculation of injury risk. The dummies were inspected after each test.

There were no signs of damage beyond normal wear and tear, and no part replacements were necessary. We did observe some sensor anomalies or failures to sensors, but almost all the sensors that failed were non-critical—for example off-axis channels (e.g., right femur X-axis force) or sensors not used in the calculation of injury criteria (e.g., lower neck load cell, foot accelerometers). See Appendix F. Such sensor anomalies can also occur in other Part 572 ATDs, such as the HIII-50M and HIII-05F used in Frontal NCAP testing. In the past six years of Frontal NCAP testing, there was an average of one failed ATD sensor channel per crash test (0.68 ± 1.08), with five of those instances occurring in a critical channel.

Many of these anomalies were the results of loose Amphenol pins. These are the electrical contacts inside of the connectors used to interface the THOR-50M umbilical cables with the specific data acquisition system of the test facility. These connectors are used to prevent the need for cutting wires and attaching lab-specific connectors each time an ATD is sent to a new facility with a different data acquisition system. In practice, ATDs sent to test facilities for the execution of regulation or consumer information testing will often remain on-site for an extended period of time, which makes laboratory-specific connectors more feasible. Such issues would not exist for THOR-50M ATDs with in-dummy data acquisition systems. Many of the sensor failures that occurred were in non-critical instrumentation, for example off-axis channels or sensors not used in the calculation of injury criteria. For research tests, a larger number of sensors are recorded for the sake of completeness and post-test investigation; in a regulatory or consumer information testing environment, these channels may not be recorded. If the user does want to record such sensors, they would need to be repaired or replaced before pre-test qualification for the next vehicle crash test.

The only sensor anomalies related to the calculation of injury criteria were in the chest and abdomen, but, once linearized, scaled, filtered, and converted to three-dimensional resultant deflection local spine coordinate system, these “blips” were

no longer evident; thus they would not influence the calculation of injury risk for this occupant. These voltage drops are characteristic of the abrupt decreases in the IR-TRACC voltage time-history described in Section III.E.2. See Appendix F.

3. FMVSS No. 208 Unbelted Vehicle Crash Tests

NHTSA performed a series of unbelted vehicle crash tests required in FMVSS No. 208. The results are briefly summarized in this section and are discussed in more detail in the referenced paper.¹⁸³ FMVSS No. 208 specifies a frontal crash test into a rigid barrier with the barrier angle at 0 degrees to ± 30 degrees at between 20 mph (32 km/h) and 25 mph (40 km/h), inclusive, with an unbelted 50th percentile male dummy seated at either front outboard seat.¹⁸⁴

NHTSA ran two sets of tests. First, we ran this test at the highest regulatory speed of 40 km/h (25 mph) for crash geometries of 30 degrees to the left, 30 degrees to the right, and perpendicular (12 tests). Second, we ran a modified version of this test, with an elevated speed of 48 km/h (30 mph) for crash geometries of 30 degrees to the left and right (six tests). We tested with two different THOR-50M ATDs, both manufactured by Humanetics and built to the 2018 drawing package (except that one ATD (EG2595) was fitted with the proposed optional in-dummy DAS). For these tests, the laboratory test procedures for FMVSS No. 208¹⁸⁵ were followed, with the exception of the seating procedure, for which the Revised THOR 50th Percentile Male Dummy Seating Procedure¹⁸⁶ was followed. The ATD was instrumented so that all injury criteria defined for the HIII-50M in FMVSS No. 208 and in the THOR-50M Injury Criteria Report could be calculated. A total of 19 tests were run on four different vehicle models

¹⁸³ Saunders, J., Parent, D., Martin, P., 2023. THOR-50M Fitness Assessment In FMVSS No. 208 Unbelted Crash Tests. In: Proceedings of the 24th International Technical Conference for the Enhanced Safety of Vehicles (No. 23-0339). Available at: <https://www-esv.nhtsa.dot.gov/Proceedings/27/27ESV-000339.pdf>.

¹⁸⁴ S14.5.2; S5.1.2(b).

¹⁸⁵ National Highway Traffic Safety Administration (2008). Laboratory Test Procedure for FMVSS 208, Occupant Crash Protection, TP208-14.

¹⁸⁶ National Highway Traffic Safety Administration (2020). Revised THOR 50th Percentile Male Dummy Seating Procedure, June 2019. *Regulations.gov* Docket ID NHTSA-2019-0106-0006, available at <https://www.regulations.gov/document/NHTSA-2019-0106-0006>.

(the Honda Accord, Mazda CX–5, Chevrolet Equinox, and Ford Escape).

This study showed that the THOR–50M, when exercised in unbelted frontal rigid barrier testing, experienced only minor issues. We performed a full set of qualification tests before the test series, a partial qualification test series¹⁸⁷ after each test, and a full qualification test series halfway through the test series. In all cases, the THOR–50Ms met the qualification specifications without need for part replacement or other refurbishment. In addition, each ATD was inspected after each test for damage and to investigate sensor anomalies. While no parts were found to be in need of replacement, there were some sensor anomalies and damage. One of the ATDs did not experience any sensor anomalies or damage during testing, while the other ATD experienced some sensor anomalies that were repairable, while others were not. The sensors that were not repaired were non-critical channels (for example, the left tibia mid-shaft X-axis accelerometer), thus a decision was made to continue testing instead of repairing or replacing the sensors, which would have caused delays in the test schedule. The quantity and severity of sensor anomalies were similar to those experienced in testing with the HIII–50M, especially considering increased sensor count and level of complexity of the THOR–50M. Aside from minor wear and tear (e.g., scrapes on the top of the head skin of one ATD were noted after one test) there was no damage to either ATD and both met all qualification specifications.

Based on these observations, NHTSA tentatively concludes that THOR–50M is sufficiently durable for use in FMVSS No. 208 unbelted testing, even at an elevated closing speed. Overall, this unbelted test series provides additional assurance that the THOR–50M units are durable and stand up well under testing, with the amount of wear and tear normal for our test dummies, and that NHTSA’s THOR–50M design specifications have resulted in highly uniform and durable units.

C. Sensitivity to Restraint System Performance

NHTSA’s testing with the THOR–50M has also highlighted its ability to detect differences in restraint system performance. One example of this occurred in the Oblique OMDB testing

¹⁸⁷ To maximize efficiency, the partial qualification test series only included the tests that did not require any disassembly of dummy components: head, upper thorax, lower thorax, lower abdomen, and left/right upper leg. The face impact test was not included because direct impact to the face was not expected during this test series.

described above in Section VII.B.2.¹⁸⁸ This testing involved vehicles of the same model and model year with a THOR–50M seated in each front outboard seat. In one series of tests which included three Oblique OMDB crash tests of the same vehicle make and model, the THOR–50Ms seated in the right front passenger seat showed a much wider variation in injury assessment values related to head injury risk than the THOR–50Ms seated in the driver’s seat. A thorough investigation of the test data, including inspection of the high-speed video, revealed that the right front passenger air bag did not function consistently to manage the ride-down of the occupant: the high-speed images revealed differences in air bag deployment, interaction between the head and the air bag, and contact between the head and the instrument panel. Inspection of the air bag revealed tears in the air bags in two of the three tests, with the largest tears associated with the highest injury assessment values.¹⁸⁹ This is one example of how the innovative features of the THOR–50M can help lead to improved vehicle safety.

VIII. Intellectual Property

While there is no specific prohibition on specifying a patented component, copyrighted design, or name-brand product in Part 572, NHTSA has been mindful of the legislative history of the Safety Act and its own responsibility under statute to make all information, patents, and developments related to a research and development activity available to the public where it makes more than a minimal contribution to the activity.¹⁹⁰ This understanding has guided dummy development at NHTSA for many years and explains why NHTSA has not incorporated into final rules materials owned by third parties except in rare cases (discussed below). The legislative history of the Safety Act shows that while Congress explicitly declined to include a provision preventing use of patents by the agency in standards, Congress did “assume[] that the Secretary is not likely to adopt a standard which can be met only by using a single patented device, and that the Secretary would, before doing so, take steps to obtain an understanding

¹⁸⁸ Saunders, J., & Parent, D. (2018). Repeatability and reproducibility of oblique moving deformable barrier test procedure (No. 2018–01–1055).

¹⁸⁹ These results were shared with the vehicle manufacturer, which instituted a series of modifications. In a later test of the vehicle, there were no passenger air bag tears evident, and the head injury criteria were similar to those measured in the previous tests that did not appear to result in air bag tears.

¹⁹⁰ 49 U.S.C. 30182(f).

from the patent holder that he would supply the item or grant licenses on reasonable terms.”¹⁹¹ In addition, NHTSA itself plays a significant role in the testing, evaluation and performance verification of dummies and provides a substantial amount of information to the public to identify the basis for improvement in testing devices to ensure the repeatability and reproducibility of results. The outcome of the agency’s involvement has been an interest in making sure the test device is available for use without restriction to the public.

To be clear, there are also several potential concerns with specifying proprietary components. They may be modified by the proprietary source such that original is no longer available, and the new part no longer fits. The proprietary source may alter the part in ways that change the response of the dummy, such that dummies with the newer part do not provide the same response as dummies with the older part. Components produced by only one manufacturer are not subject to competitive sales pressures. And the manufacturer of a sole-source part may simply cease manufacturing the part.

For these reasons, NHTSA has generally avoided specifying in Part 572 patented components or copyrighted designs without either securing agreement from the rights-holder for the free use of the item or to license it on reasonable terms¹⁹² or developing an alternative unencumbered by any rights claims.¹⁹³

As noted earlier in the preamble (Section III), we are specifying some patented parts but not without specifying suitable alternates where no intellectual property claims apply. We briefly discuss these below.

Shoulder

As explained earlier, we are proposing to include two alternative shoulder specifications: the SD–3 shoulder and the alternate shoulder.

Humanetics has two patents on the SD–3 shoulder: one describes a mechanical shoulder joint assembly and the other describes an upper arm

¹⁹¹ S. Rep. No. 89–1301, at 15, reprinted in U.S.C.C.A.N. 2709, 2723.

¹⁹² See, e.g., 38 FR 8455 (Apr. 2, 1973) (NPRM for the initial 50th percentile male dummy) (“To the knowledge of this agency, the only patent on a component of the specified dummy is one on the knee held by Alderson, and that company has stated to the NHTSA that it will license production under its patent for a reasonable royalty.”)

¹⁹³ See, e.g., 65 FR 17180, 17187 (Mar. 31, 2000) (final rule for twelve-month-old child dummy) (declining to incorporate a copyrighted PADI developed by an ATD manufacturer and instead incorporating a NHTSA-authored PADI).

assembly with a load cell.¹⁹⁴ The shoulder joint is formed using a pivot connected to a spring element inside of a housing, which has an adjustable element to control the friction of the joint. Humanetics is currently the sole manufacturer of the SD-3 shoulder in the United States.

In order to avoid potential concerns with specifying a patented part as the sole specification, NHTSA has developed an alternative to the SD-3 shoulder. The alternate shoulder does not include the adjustable friction element, and does not use a coil, clock, or watch spring mechanism. Instead, the alternate shoulder design uses a molded rubber cylinder acting as a torsion bar. The response of the rubber cylinder can be tuned by both changes in material and changes in geometry, such as removal of material to create voids of different sizes and shapes. This lack of a friction adjustment in the alternate shoulder is a change in the functional aspect of the design. Accordingly, with the significant differences noted, we are proposing to specify the use of either the alternate shoulder or the SD-3 shoulder.

Chest Instrumentation

NHTSA is proposing the IR-TRACC and the S-Track as permissible alternate

instrumentation. While NHTSA is not aware of any patent protection on the IR-TRACC, it is manufactured only by Humanetics. There is a patent on the S-Track, and NHTSA’s understanding is that the S-Track is currently manufactured only by ATD-LabTech, which was recently acquired by Humanetics.

We believe that specifying the design such that either the IR-TRACC or the S-Track could be used would be sufficient to ensure instrumentation availability to dummy users. We seek comment on this.

IX. Consideration of Alternatives

NHTSA is not aware of a 50th percentile male ATD intended for use in frontal or frontal oblique crash tests and more advanced than the HIII-50M, other than the THOR-50M. Throughout this document we have discussed various alternative configurations, specifications, and tests that we have considered in developing the proposal and on which we are seeking comment.

As discussed in more detail in the rulemaking analyses section, Executive Order 13609 provides that international regulatory cooperation can reduce, eliminate, or prevent unnecessary differences in regulatory requirements. Similarly, § 24211 of the Infrastructure,

Investment, and Jobs Act¹⁹⁵ instructs DOT to harmonize the FMVSS with global regulations to the maximum extent practicable (for example, to the extent that harmonization would be consistent with the Safety Act).

The only regulatory authority or consumer ratings program we are aware of that currently uses the THOR-50M is Euro NCAP. Euro NCAP TB026 references the August 2018 drawing package,¹⁹⁶ the September 2018 Qualification Procedures,¹⁹⁷ and the August 2018 PADI.¹⁹⁸ Although TB026 largely follows these documents, it does depart from them in several ways. Those differences have been identified and discussed in the relevant sections of the preamble and are summarized in Table 20. The tentative reasons for those differences are explained in detail in the relevant section of the preamble. In general, we believe that those differences are justified given NHTSA’s experience testing with the THOR-50M in frontal rigid barrier and frontal oblique vehicle crash test modes, and the necessity of ensuring that a dummy specified for use in regulatory compliance testing be objectively specified.

TABLE 20—SUMMARY OF DIFFERENCES BETWEEN THE THOR-50M AS PROPOSED AND AS SPECIFIED FOR USE IN EURO NCAP

Issue	Proposal	Euro NCAP
Design & Construction:		
Split shoulder pad	Not proposed	Under consideration.
Spine	Spine Pitch Change Joint	Four-Position Spine Box.
Lower Leg	THOR-specific lower leg	HIII-50M lower leg.
Instrumentation:		
S-Track/IR-TRACC	IR-TRACC or S-Track	IR-TRACC, S-Track, or KIR-TRACC
		Does not specify the systems part-by-part with engineering drawings.
In-dummy DAS	Permitted as optional configuration with part-by-part engineering drawings compatible with the SLICE6 and any other similarly-configured system.	TB026 requires an in-dummy DAS. TB029 currently does not specify any specific in-dummy DAS, although earlier versions of TB029 did specify a few different approved in-dummy DAS systems.
		Does not specify the systems part-by-part with engineering drawings.
Qualification Tests:		
Acceptance interval midpoint	Based on R&R test data	Basis not identified in TB026.
Acceptance interval width	± 10% of midpoint	Varies from ±1% to ±10%.
Upper thorax	Ratio of Z-axis to X-axis deflection not specified as test parameter.	Specifies ratio of Z-axis to X-axis deflection as test parameter.
Face impact test	Specified	Not specified.
Knee slider	Specified	Certified to SAE J2876.
Lower legs	Ankle inversion/eversion; Ball of foot; heel	Certified to Annex 10 of ECE Regulation No. 94.

¹⁹⁴ U.S. Patent Nos. 9,514,659 (upper arm assembly) and 9,799,234 (shoulder joint assembly).

¹⁹⁵ H.R. 3684 (117th Congress) (2021).

¹⁹⁶ § 1.1.

¹⁹⁷ § 2.1.

¹⁹⁸ § 3.1.

X. Lead Time

Since this rulemaking action itself would not impose requirements on anyone, we are proposing that the final rule would be effective on publication in the **Federal Register**.

XI. Incorporation by Reference

Under regulations issued by the Office of the Federal Register (1 CFR 51.5(a)), an agency, as part of a final rule that includes material incorporated by reference, must summarize in the preamble of the final rule the material it incorporates by reference and discuss the ways the material is reasonably available to interested parties or how the agency worked to make materials available to interested parties.

In this proposed rule, NHTSA incorporates by reference a technical data package for the THOR–50M. The technical data package consists of two-dimensional engineering drawings and a parts list; procedures for assembly, disassembly, and inspection (PADI); and qualification procedures. Copies of these documents are available in the research docket identified earlier in this document. Interested persons can download a copy of the materials or view the materials online by accessing www.Regulations.gov. The material is also available for inspection at the Department of Transportation, Docket Operations, Room W12–140, 1200 New Jersey Avenue SE, Washington, DC Telephone: 202–366–9826. If the proposed rule is finalized, final versions of these documents would be placed in a docket that would be readily available to the public online (via regulations.gov) and in-person at DOT headquarters.

Although agency-created documents are presumptively ineligible for incorporation by reference, they may be approved for incorporation by the Office of the Federal Register if they (among other things) consist of criteria, specifications, or illustrations; are reasonably available to the class of persons affected; are easy to handle; and possesses other unique or highly unusual qualities.¹⁹⁹

¹⁹⁹ See 1 CFR 51.7(b) (“The Director will assume that a publication produced by the same agency that is seeking its approval is inappropriate for incorporation by reference. A publication produced by the agency may be approved, if, in the judgment of the Director, it meets the requirements of paragraph (a) and possesses other unique or highly unusual qualities. A publication may be approved if it cannot be printed using the **Federal Register**/Code of Federal Regulations printing system.”); (a)(2)(i) (“published data, criteria, standards, specifications, techniques, illustrations, or similar material”); (a)(3) (“reasonably available to and usable by the class of persons affected”); (a)(3)(i) (“The completeness and ease of handling of the publication”).

We believe these documents (which were created by NHTSA) meet these criteria. Except for the qualification procedures, NHTSA typically incorporates these elements of the technical data package by reference. NHTSA has not typically incorporated the qualification procedures by reference. Doing so is a departure from the other ATDs currently specified in Part 572, for which the qualification tests are set out in full in the regulatory text in each of the relevant paragraphs (corresponding to that ATD) in part 572. We are proposing a separate qualification procedures document for the THOR–50M because the THOR–50M qualification procedures involve procedures that are made clearer by photographs and diagrams that are not amenable to publication in the CFR.²⁰⁰ We believe this extra level of detail will be helpful for end users who are attempting to qualify the ATD. We seek comment on this.

XII. Regulatory Analyses

Executive Order (E.O.) 12866, E.O. 13563, E.O. 14094, and DOT Regulatory Policies and Procedures

NHTSA has considered the impacts of this regulatory action under Executive Orders 12866, 13563, 14094, and the Department of Transportation’s regulatory policies and procedures.²⁰¹ This rulemaking action was not reviewed by the Office of Management and Budget under E.O. 12866. It is also not considered “of special note to the Department” under DOT Order 2100.6A. We have considered the qualitative costs and benefits of the proposed rule under the principles of E.O. 12866.

This document would amend 49 CFR part 572 by adding design and performance specifications for an advanced test dummy representative of a 50th percentile adult male that the agency would possibly use in FMVSS No. 208 front crash tests and for research purposes. This Part 572 proposed rule would not impose any requirements on anyone. Businesses are affected only if they choose to manufacture or test with the dummy.

There are benefits associated with this rulemaking but they are not readily quantifiable. The THOR–50M is an advanced dummy with advantages over existing dummies with respect to biofidelity, instrumentation, injury

²⁰⁰ The qualification procedures document states that the photographs are provided for reference only.

²⁰¹ 49 CFR, Part 5, Subpart B; Department of Transportation Order 2100.6A, Rulemaking and Guidance Procedures, June 7, 2021.

prediction, and evaluation of vehicle performance. The dummy is currently used for testing by Euro NCAP, and may be incorporated in ECE R137. It is also likely being used by vehicle and restraint manufacturers for testing, research, and development.

Accordingly, NHTSA is considering a proposal to incorporate the THOR–50M into FMVSS No. 208, “Occupant crash protection,” for use in frontal crash compliance testing at the manufacturers’ option.²⁰² This contemplated rulemaking action would permit manufacturers to direct NHTSA to use the THOR–50M in belted and unbelted barrier crash testing of the vehicles they produce instead of the HIII–50M ATD in NHTSA’s compliance tests. Incorporating the dummy in Part 572 will enable manufacturers and others to streamline testing, choosing to use THOR–50M in place of the HIII–50M, potentially reducing the number of tests they run, and leveraging the value of the tests they do run.

Incorporating the THOR–50M into Part 572 would also have other benefits beyond use in NHTSA’s compliance testing. The ability of the THOR–50M to potentially monitor additional injury modes and its improved biofidelity may facilitate the development and introduction of innovative occupant crash protection features. While the purpose of Part 572 is to “describe the anthropomorphic test devices that are to be used for compliance testing of motor vehicles and motor vehicle equipment with motor vehicle safety standards,” it also serves as a definition of the ATD for other purposes as well, such as consumer information crash testing, standards and regulations in other transportation modes, and research. As such, it would be to the benefit of government, academia, and the multi-modal transportation industry to include a definition of the THOR–50M ATD in Part 572. In addition, the availability of this dummy in a regulated format would be beneficial by providing a suitable, stabilized, and objective test tool to the safety community for use in better protecting occupants in frontal impacts.

The costs associated with the THOR–50M only affect those who choose to use the THOR–50M. This rule would not impose any requirements on anyone. If incorporated into FMVSS No. 208, NHTSA would use the dummy in its compliance testing of the requirements

²⁰² FMVSS No. 208 THOR–50M Compliance Option (RIN 2127–AM21), Fall 2023 Unified Agenda of Regulatory and Deregulatory Actions; Department of Transportation, available at <https://www.reginfo.gov/public/do/eAgendaViewRule?pubId=202304&RIN=2127-AM21>.

at the option of a regulated entity, but regulated entities are not required to use the dummy or assess the performance of their products in the manner specified in the FMVSSs.

NHTSA has found that the cost of a THOR-50M corresponding to the 2023 drawing package has been approximately \$550,000 to \$750,000 depending on whether an in-dummy DAS is installed and the level of instrumentation. The minimum set of instrumentation needed for qualification testing includes 66 channels. If the S-Track were used instead of the IR-TRACC, the total cost would be roughly the same.

In addition to these costs, as with any ATD, dummy refurbishments and part replacements are an inherent part of ATD testing. Various parts will likely have to be refurbished or replaced, but we generally do not know which parts are likely to be worked on the most. As we note in the NPRM, however, the face foam appears to need more frequent replacement but this should not add appreciably to the overall cost. Because the dummies are designed to be reusable, costs of the dummies and of parts can be amortized over a number of tests. While the expected maintenance costs for the THOR-50M are expected to be higher than those for less complex dummies such as the HIII-50M, these costs are expected to be similar to advanced dummies such as the WorldSID.

There are minor costs associated with conducting the qualification tests. Most of the qualification fixtures are common with those used to qualify other Part 572 dummies (including the neck pendulum and the probes used in the head, upper thorax and lower thorax tests). Some additional equipment unique to the THOR-50M may be fabricated from drawings within the technical data package, for an estimated cost of about \$50,000. This includes the cost to fabricate the torsion fixture for the neck torsion test, the lower abdomen probe face assembly, impact probes not used for other Part 572 dummies (or weighted collars to achieve the specified mass), and test apparatus for the lower leg tests (including the dynamic impactor, external positioning bracket, dynamic inversion/eversion bracket, lower leg mounting bracket, lower leg zero bracket, Achilles fixture, load cell mounting assembly, knee slider load distribution bracket, and tibia adapter). The costs of the instrumentation equipment needed to perform the qualification tests amounts to about an additional \$4,400 (two angular rate sensors, \$850 apiece; two test probe

accelerometers, \$800 apiece; one rotary potentiometer, \$1,100).

Regulatory Flexibility Act

Pursuant to the Regulatory Flexibility Act (5 U.S.C. 601 *et seq.*, as amended by the Small Business Regulatory Enforcement Fairness Act (SBREFA) of 1996), whenever an agency is required to publish a proposed or final rule, it must prepare and make available for public comment a regulatory flexibility analysis that describes the effect of the rule on small entities (*i.e.*, small businesses, small organizations, and small governmental jurisdictions), unless the head of the agency certifies the rule will not have a significant economic impact on a substantial number of small entities. The Small Business Administration's regulations at 13 CFR part 121 define a small business, in part, as a business entity "which operates primarily within the United States." (13 CFR 121.105(a)).

We have considered the effects of this rulemaking under the Regulatory Flexibility Act. I hereby certify that this rulemaking action would not have a significant economic impact on a substantial number of small entities. This action would not have a significant economic impact on a substantial number of small entities because the addition of the test dummy to Part 572 would not impose any requirements on anyone. This NPRM only proposes to include the dummy in NHTSA's regulation for crash test dummies; it does not propose NHTSA's use of the ATD in agency testing or require anyone to manufacture the dummy or to test motor vehicles or motor vehicle equipment with it.

National Environmental Policy Act

NHTSA has analyzed this proposed rule for the purposes of the National Environmental Policy Act and determined that it would not have any significant impact on the quality of the human environment.

Executive Order 13045 and 13132 (Federalism)

Executive Order 13045 (62 FR 19885, April 23, 1997) applies to any rule that: (1) is determined to be "economically significant" as defined under E.O. 12866, and (2) concerns an environmental, health, or safety risk that NHTSA has reason to believe may have a disproportionate effect on children. If the regulatory action meets both criteria, we must evaluate the environmental health or safety effects of the planned rule on children and explain why the planned regulation is preferable to other

potentially effective and reasonably feasible alternatives considered by us.

This proposed rule is not subject to the Executive Order because it is not economically significant as defined in E.O. 12866.

NHTSA has examined this proposed rule pursuant to Executive Order 13132 (64 FR 43255, August 10, 1999) and concluded that no additional consultation with States, local governments or their representatives is mandated beyond the rulemaking process. The agency has concluded that the proposed rule would not have federalism implications because the proposed rule would not have "substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government." This proposed rule would not impose any requirements on anyone. Businesses will be affected only if they choose to manufacture or test with the dummy.

Further, no consultation is needed to discuss the preemptive effect of this proposed rule. While NHTSA's safety standards can have preemptive effect, the proposed rule would amend 49 CFR part 572 and is not a safety standard. This Part 572 proposed rule would not impose any requirements on anyone.

Civil Justice Reform

With respect to the review of the promulgation of a new regulation, section 3(b) of Executive Order 12988, "Civil Justice Reform" (61 FR 4729, February 7, 1996) requires that Executive agencies make every reasonable effort to ensure that the regulation: (1) Clearly specifies the preemptive effect; (2) clearly specifies the effect on existing Federal law or regulation; (3) provides a clear legal standard for affected conduct, while promoting simplification and burden reduction; (4) clearly specifies the retroactive effect, if any; (5) adequately defines key terms; and (6) addresses other important issues affecting clarity and general draftsmanship under any guidelines issued by the Attorney General. This document is consistent with that requirement.

Pursuant to this Order, NHTSA notes as follows.

The issue of preemption is discussed above in connection with E.O. 13132. NHTSA notes further that there is no requirement that individuals submit a petition for reconsideration or pursue other administrative proceeding before they may file suit in court.

Paperwork Reduction Act

Under the Paperwork Reduction Act of 1995, a person is not required to respond to a collection of information by a Federal agency unless the collection displays a valid control number from the Office of Management and Budget (OMB). This proposed rule would not have any requirements that are considered to be information collection requirements as defined by the OMB in 5 CFR part 1320.

National Technology Transfer and Advancement Act

Section 12(d) of the National Technology Transfer and Advancement Act of 1995 (NTTAA), Public Law 104–113, section 12(d) (15 U.S.C. 272) directs NHTSA to use voluntary consensus standards in its regulatory activities unless doing so would be inconsistent with applicable law or otherwise impractical. Voluntary consensus standards are technical standards (*e.g.*, materials specifications, test methods, sampling procedures, and business practices) that are developed or adopted by voluntary consensus standards bodies. The NTTAA directs NHTSA to provide Congress, through OMB, explanations when the agency decides not to use available and applicable voluntary consensus standards.

The following voluntary consensus standards have been used in developing the THOR–50M:

- SAE J211–1, Instrumentation for impact test—Part 1: Electronic Instrumentation, Version 2014–03–31
- SAE J1733, Sign Convention for Vehicle Crash Testing, Version 2007–11–02.
- SAE J2570, Performance specifications for anthropomorphic test device transducers, Version 2009–08–12.
- SAE J2876, Low Speed Knee Slider Test Procedure for the Hybrid III 50th Male Dummy, Version 2015–05–07.
- ISO–MME Task Force, 2015–04–15 proposed mnemonic codes for the THOR–50M.

Unfunded Mandates Reform Act

The Unfunded Mandates Reform Act of 1995 (Pub. L. 104–4) (UMRA) requires agencies to prepare a written assessment of the costs, benefits, and other effects of proposed or final rules that include a Federal mandate likely to result in the expenditures by States, local or tribal governments, in the aggregate, or by the private sector, of \$100 million or more (adjusted annually for inflation with base year of 1995) in any one year. Adjusting this amount by

the implicit gross domestic product price deflator for 2022 results in \$177 million ($111.416/75.324 = 1.48$). The assessment may be included in conjunction with other assessments, as it is here. UMRA requires the agency to select the “least costly, most cost-effective or least burdensome alternative that achieves the objectives of the rule.”

This proposed rule would not impose any unfunded mandates under the UMRA. This proposed rule does not meet the definition of a Federal mandate because it does not impose requirements on anyone. It amends 49 CFR part 572 by adding design and performance specifications for a 50th percentile adult male frontal crash test dummy that the agency could use in FMVSS No. 208 and for research purposes. This proposed rule would affect only those businesses that choose to manufacture or test with the dummy. It would not result in costs of \$100 million or more (adjusted for inflation) to either State, local, or tribal governments, in the aggregate, or to the private sector.

Plain Language

Executive Order 12866 and E.O. 13563 require each agency to write all rules in plain language. Application of the principles of plain language includes consideration of the following questions:

- Have we organized the material to suit the public’s needs?
- Are the requirements in the rule clearly stated?
- Does the rule contain technical language or jargon that isn’t clear?
- Would a different format (grouping and order of sections, use of headings, paragraphing) make the rule easier to understand?
- Would more (but shorter) sections be better?
- Could we improve clarity by adding tables, lists, or diagrams?
- What else could we do to make the rule easier to understand?

If you have any responses to these questions, please include them in your comments on this proposal.

Regulation Identifier Number

The Department of Transportation assigns a regulation identifier number (RIN) to each regulatory action listed in the Unified Agenda of Federal Regulations. The Regulatory Information Service Center publishes the Unified Agenda in April and October of each year. You may use the RIN contained in the heading at the beginning of this document to find this action in the Unified Agenda.

Privacy Act

In accordance with 5 U.S.C. 553(c), DOT solicits comments from the public to better inform its rulemaking process. DOT posts these comments, without edit, to www.regulations.gov, as described in the system of records notice, DOT/ALL–14 FDMS, accessible through www.dot.gov/privacy. In order to facilitate comment tracking and response, we encourage commenters to provide their name, or the name of their organization; however, submission of names is completely optional. 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 (Volume 65, Number 70; Pages 19477–78).

XIII. Public Participation*How do I prepare and submit comments?*

Your comments must be written and in English. To ensure that your comments are correctly filed in the Docket, please include the agency name and the docket number or Regulatory Identification Number (RIN) in your comments.

Your comments must not be more than 15 pages long. (49 CFR 553.21). We 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.

If you are submitting comments electronically as a PDF (Adobe) file, NHTSA asks that the documents be submitted using the Optical Character Recognition (OCR) process, thus allowing NHTSA to search and copy certain portions of your submissions.

Please note that pursuant to the Data Quality Act, in order for substantive data to be relied upon and used by the agency, it must meet the information quality standards set forth in the OMB and DOT Data Quality Act guidelines. Accordingly, we encourage you to consult the guidelines in preparing your comments. OMB’s guidelines may be accessed at <https://www.transportation.gov/regulations/dot-information-dissemination-quality-guidelines>.

How can I be sure that my comments were received?

If you wish the Docket to notify you upon its receipt of your comments, enclose a self-addressed, stamped postcard in the envelope containing your comments. Upon receiving your comments, the Docket will return the postcard by mail.

How do I submit confidential business information?

You should submit a redacted “public version” of your comment (including redacted versions of any additional documents or attachments) to the docket using any of the methods identified under **ADDRESSES**. This “public version” of your comment should contain only the portions for which no claim of confidential treatment is made and from which those portions for which confidential treatment is claimed has been redacted. See below for further instructions on how to do this.

You also need to submit a request for confidential treatment directly to the Office of Chief Counsel. Requests for confidential treatment are governed by 49 CFR part 512. Your request must set forth the information specified in Part 512. This includes the materials for which confidentiality is being requested (as explained in more detail below); supporting information, pursuant to Part 512.8; and a certificate, pursuant to Part 512.4(b) and Part 512, Appendix A.

You are required to submit to the Office of Chief Counsel one unredacted “confidential version” of the information for which you are seeking confidential treatment. Pursuant to Part 512.6, the words “ENTIRE PAGE CONFIDENTIAL BUSINESS INFORMATION” or “CONFIDENTIAL BUSINESS INFORMATION CONTAINED WITHIN BRACKETS” (as applicable) must appear at the top of each page containing information claimed to be confidential. In the latter situation, where not all information on the page is claimed to be confidential, identify each item of information for which confidentiality is requested within brackets: “[.]”

You are also required to submit to the Office of Chief Counsel one redacted “public version” of the information for which you are seeking confidential treatment. Pursuant to Part 512.5(a)(2), the redacted “public version” should include redactions of any information for which you are seeking confidential treatment (*i.e.*, the only information that should be unredacted is information for which you are not seeking confidential treatment).

NHTSA is currently treating electronic submission as an acceptable

method for submitting confidential business information to the agency under Part 512. Please do not send a hardcopy of a request for confidential treatment to NHTSA’s headquarters. The request should be sent to Dan Rabinovitz in the Office of the Chief Counsel at Daniel.Rabinovitz@dot.gov. You may either submit your request via email or request a secure file transfer link. If you are submitting the request via email, please also email a courtesy copy of the request to John Piazza at John.Piazza@dot.gov.

Will the agency consider late comments?

We will consider all comments received before the close of business on the comment closing date indicated above under **DATES**. To the extent possible, we will also consider comments that the docket receives after that date. If the docket receives a comment too late for us to consider in developing a final rule (assuming that one is issued), we will consider that comment as an informal suggestion for future rulemaking action.

How can I read the comments submitted by other people?

You may read the comments received by the docket 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. To read the comments on the internet, go to <http://www.regulations.gov>. Follow the online instructions for accessing the dockets.

Please note that even after the comment closing date, we will continue to file relevant information in the docket as it becomes available. Further, some people may submit late comments. Accordingly, we recommend that you periodically check the Docket for new material. You can arrange with the docket to be notified when others file comments in the docket. See www.regulations.gov for more information.

List of Subjects in 49 CFR Part 572

Motor vehicle safety, Incorporation by reference.

Proposed Regulatory Text

In consideration of the foregoing, NHTSA proposes to amend 49 CFR part 572 as follows:

PART 572—ANTHROPOMORPHIC TEST DEVICES

■ 1. The authority citation for part 572 continues to read as follows:

Authority: 49 U.S.C. 322, 30111, 30115, 30117 and 30166; delegation of authority at 49 CFR 1.95.

■ 2. Add Subpart X, consisting of §§ 572.220 through 572.221, to read as follows:

Subpart X—THOR—50M 50th Percentile Male Frontal Impact Test Dummy

Secs.

572.220 Incorporation by reference.

572.221 General description.

Subpart X—THOR—50M 50th Percentile Male Frontal Impact Test Dummy

§ 572.220 Incorporation by reference.

Certain material is incorporated by reference (IBR) into this part with the approval of the Director of the Federal Register under 5 U.S.C. 552(a) and 1 CFR part 51. To enforce any edition other than that specified in this section, NHTSA must publish a document in the **Federal Register** and the material must be available to the public. This material is available for inspection at the Department of Transportation, the National Archives and Records Administration (NARA), and in electronic format through regulations.gov. Contact DOT at: Department of Transportation, Docket Operations, Room W12–140, 1200 New Jersey Avenue SE, Washington DC 20590, telephone 202–366–9826. For information on the availability of this material at NARA, email fr.inspection@nara.gov or go to www.archives.gov/federal-register/cfr/ibr-locations. To locate the material on regulations.gov, search for Docket No. NHTSA–202X–XXXX. The material may be obtained from the source:

(a) NHTSA Technical Information Services, 1200 New Jersey Ave. SE, Washington, DC 20590, telephone 202–366–5965.

(1) A drawing package entitled, “THOR–50th Percentile Male with Alternate Shoulders Frontal Crash Test Dummy (THOR–50M Male w/Alt. Shoulders) Drawings, External Dimensions, and Mass Properties,” dated (and revised) January 2023 (Drawings and Specifications); IBR approved for § 572.221.

(2) A parts list entitled, “Parts List, THOR–50th Percentile Male Frontal Crash Test Dummy with Alternate Shoulders (THOR–50M w/Alt. Shoulders)” dated (and revised) January 2023 (Parts List); IBR approved for § 572.221.

(3) A procedures document entitled “THOR 50th Percentile Male (THOR–50M) Procedures for Assembly, Disassembly, and Inspection (PADI)” dated (and revised) June 2023 (PADI); IBR approved for § 572.221.

(4) A procedures document entitled “THOR 50th Percentile Male (THOR–50M) Qualification Procedures and Requirements” dated (and revised) April 2023 (Qualification Procedures); IBR approved for § 572.221.

§ 572.221 General description.

(a) The THOR–50M 50th percentile male test dummy is defined by the following materials:

(1) The Drawings and Specifications (incorporated by reference, see § 572.220);

(2) The Parts List (incorporated by reference, see § 572.220);

(3) The PADI (incorporated by reference, see § 572.220);

(4) The Qualification Procedures (incorporated by reference, see § 572.220).

Issued under authority delegated in 49 CFR 1.95, 501.4, and 501.

Ann Carlson,

Acting Administrator.

[FR Doc. 2023–19008 Filed 9–6–23; 8:45 am]

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