THOR-50M FITNESS ASSESSMENT IN FMVSS NO. 208 UNBELTED CRASH TESTS

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ABSTRACT

Research Question/Objective: A prerequisite for entering a dummy design into CFR Title 49, Part 572 is to demonstrate that the specifications yield ATD units capable of implementation in a regulatory environment. Specifications for the THOR-50M have produced units that are repeatable, reproducible, and durable in many test conditions, including belted sled tests and qualification testing. Herein, two THOR-50M units are implemented in a series of unbelted vehicle crash tests run in accordance with FMVSS No. 208 procedures, and evaluated based on usability, durability, and the successful collection of sensor data for use in injury risk prediction.

Methods and Data Sources: Two THOR-50M units, both conforming to NHTSA's 2018 THOR-50M design and qualification specifications, were run in a series of unbelted crash tests. Nineteen tests were run with four 2020-21 vehicle models: Honda Accord, Mazda CX-5, Chevy Equinox, Ford Escape. Four were run against a full-frontal barrier and fourteen against an angled barrier in accordance with FMVSS No. 208 procedures, with the exception of using NHTSA's THOR 50th Percentile Male Dummy Seating Procedure instead of using FMVSS No. 208 seating. Dummy qualifications were performed periodically throughout the test series following NHTSA's THOR-50M Qualification Procedures.

Results: The two units held up well to the rigors of the crash tests. Both were fully instrumented, one of which included an internal DAS system. Sensor anomalies and failures during tests were traced to cable damage, which was repaired between tests. The parts and assemblies within both units did not sustain any damage beyond scuffs and cuts to exterior vinyl components. There were no parts that needed to be replaced. Dummy qualifications posed no issues. The test lab was able to maintain a testing schedule typical of other regulatory tests with other types of dummies.

Discussion and Limitations: This test series demonstrated that the THOR-50M could be implemented in vehicle crash testing consistent with regulatory compliance testing in that the ATDs showed sufficient usability and durability. Both units successfully collected sensor data for use in injury risk prediction. The minor sensor anomalies that did occur were mostly isolated to the ATD without the internal DAS system. A limitation of this study was that only four vehicle models were tested and all tests were run at a single lab.

Conclusions and Relevance to Session Submitted: In a series of FMVSS No. 208 unbelted frontal rigid barrier crash tests, two THOR-50M units were implemented and successfully completed the test series. Scripted procedures for dummy assembly, qualification, and handling were followed without issue, and the seating procedures resulted in highly uniform positioning. Sensor anomalies observed over the course of testing were consistent with those common in dummies already in Part 572. There were no broken parts or part replacements throughout testing. Based on the experiences of this testing series, the THOR-50M appears fit for use in standardized testing.

INTRODUCTION

NHTSA has performed many types of research tests using the Test Device for Human Occupant Restraint 50th percentile male (THOR-50M) anthropomorphic test device (ATD). These include belted THOR-50M in the front and rear seat in both full vehicle and sled tests and different types of frontal research crash testing to develop new test procedures [1][2]. This included vehicle-to-vehicle with overlaps from 20 percent to 100 percent overlap and at different impact angles [3]. It also included tests involving moving deformable barriers into the front of a vehicle in overlap and oblique conditions [4]. In addition, the durability of the THOR-50M has been observed in a wide array of component, sled, and vehicle crash test conditions [5][6].

More recently, NHTSA used the THOR-50M in crash tests in a new series of tests that were very similar to those specified in FMVSS No. 208, Occupant Crash Protection. The most recent series included unbelted THOR-50M positioned in the front seat of a vehicle into a rigid barrier. The THOR-50M had been tested previously in the driver seat in the frontal rigid barrier test procedure and in unbelted sled test conditions. But until the new test series discussed herein, the dummy had not been included in unbelted vehicle crash tests following the FMVSS No. 208 test procedures.

An objective of the unbelted test series was to evaluate the fitness of the THOR-50M in a standardized testing environment for codification within CFR Title 49, Part 572, Anthropomorphic Test Devices. This paper summarizes the THOR-50M testing experience under conditions similar to the way Part 572 ATDs are used by NHTSA to carry out regulatory tests. This includes how the THOR-50M qualified before and after testing, any damage to the THOR-50M, instrumentation performance, and any issues with performing the tests.

METHODOLOGY

Overview

Two THOR-50M units, both conforming to NHTSA's 2018 THOR-50M design specifications [7][8], were run in a series of unbelted crash tests. Nineteen full-scale vehicle crash tests were run with four 2020-21 models: Honda Accord, Mazda CX-5, Chevy Equinox, Ford Escape. Four were run against a full-frontal rigid barrier and the others were run against an angled, rigid barrier. Details of the tests are discussed below.

Unbelted Rigid Barrier Tests

The nineteen tests were run by following FMVSS No. 208 procedures for the unbelted driver and right front passenger seating positions [9]. For reference, the FMVSS No. 208 unbelted crash configurations are shown in Figure 1.

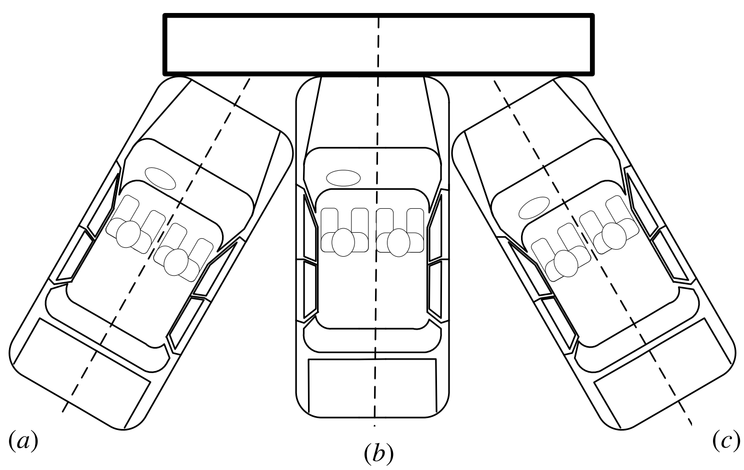

Figure 1. FMVSS No. 208, unbelted crash test configurations:

a) Left side impact with the rigid barrier angle set at 30º.
b) Full frontal impact with the rigid barrier angle set at 0º.
c) Right side impact with the rigid barrier angle set at 30º.
Impact speed: 32-40 km/hr for all three configurations

Each crash test was performed following the test procedure specified in FMVSS No. 208, with the following exceptions:

• THOR-50M units were used in the driver and front passenger seating positions, and they were positioned according to the Revised THOR 50th Percentile Male Dummy Seating Procedure [10].

• In FMVSS No. 208, the vehicle impact speed specified for these tests is 32-40 km/hr (20-25 mph), but all tests run in this test series described herein were run at either 40 km/hr or 48 km/hr. Although 48 km/hr is above the maximum regulatory speed, six tests were run at the higher speed to assess the integrity of the THOR-50M when exposed to energy levels above and beyond those prescribed by the standard.

Table A-1 in the Appendix provides a list of summary information for each of the nineteen crash tests.

THOR-50M Units Tested

During this test series, two different THOR-50M ATDs were used, identified by their serial numbers: DO9799 and EG2595. Both were manufactured by Humanetics in accordance with NHTSA's Parts List and Drawings [7]. After EG2595 was delivered to NHTSA in 2018, the dummy was sent to Diversified Technical Systems, Inc. (DTS) for installation of an in-dummy data acquisition system (DAS) based on the SLICE6 DAS modules.

Both dummies were instrumented and assembled at NHTSA's Dummy Management Laboratory (DML) at the Vehicle Research and Test Center (VRTC) in Ohio prior to delivery to the crash test lab, Applus-Idiada-Karco Engineering, Adelanto, CA. Final assembly (including joint torque settings), wire harness routing, and instrumentation polarity checks were fulfilled at Applus-Idiada-Karco by following NHTSA's THOR-50M Procedures for Assembly, Disassembly, and Inspection (PADI) [11]. For EG2595, NHTSA provided a DTS Mini Distributor with cables and PSU to facilitate download and storage of test data by Applus-Idiada-Karco.

The instrumentation included head accelerometers, head angular rate sensors, upper and lower neck load cells, T1 and T6 accelerometers, chest and abdomen 3D IR-TRACC assemblies, thoracic spine load cell, ASIS load cells, acetabulum load cells, and femur load cells (about 130 channels in all). All of these instruments are specified within the drawing package, with installation instructions included in the PADI. Additionally, both units were instrumented with sensors to measure the internal temperature before, during, and after testing. The full list of instrumentation is provided in the individual vehicle test reports.

THOR-50M Qualification and Inspection

Prior to the initial vehicle crash test at Applus-Idiada-Karco, a full set of qualification tests was conducted on each THOR-50M at NHTSA's DML Thereafter, a partial qualification test series was conducted after each vehicle crash test by Applus-Idiada-Karco on the THOR-50M units(s) that were used in the crash.

The partial set included most of the full-body test modes as shown in Table 1. A full qualification test series was also conducted on each THOR-50M halfway through the test series at Applus-Idiada-Karco. All qualification tests were carried out in accordance with NHTSA's THOR-50M Qualification Procedures [8]. Also, before every test, a full polarity check was performed to assure that all sensors were working properly.

After every crash test, the THOR-50M unit(s) underwent a physical inspection at Applus-Idiada-Karco. Each body region was examined by partially disassembling the dummy. An approximate 60-point visual inspection was carried out. Photographic images of any and all damage are documented in each test report.

As part of the inspection, each sensor was scrutinized for its overall condition and functionality. This was determined by examining crash test signal data channels for any sensor anomalies, such as clipping, unexpected drops, or flat signals. Instruments were also inspected for any physical evidence of damage. If any damage or sensor anomalies were found, the instruments were closely inspected to determine the source of the anomaly (typically, a loose wire) and repaired where possible.

Table 1. THOR-50M Qualification Tests and Requirements.

Dummy test assembly	Body region	No. of qualif. requirements
Full dummy	Face	2
Full dummy	Head*	2
Full dummy	Upper thorax*	4
Full dummy	Lower thorax*	2
Full dummy	Lower abdomen*	3
Full dummy	Upper leg (R and L)*	3
Head/neck sub-assembly	Neck extension	4
Head/neck sub-assembly	Neck flexion	4
Head/neck sub-assembly	Neck lateral flexion (R, L)	3
Neck assembly only	Neck torsion (R and L)	3
Knee assembly only	Knee (R and L)	2
Lower leg only (no shoe)	Ankle eversion (R and L)	3
Lower leg only (no shoe)	Ankle inversion (R and L)	3
Lower leg only (incl. shoe)	Heel (R and L)	1
Lower leg only (incl. shoe)	Ball of foot (R and L)	3

**Included in Partial set of qualifications*

THOR-50M Crash Test Exposures

For the three FMVSS No. 208 unbelted test configurations (right 30° angle, left 30° angle, frontal 0°), the two THOR-50M units were subjected to multiple crash exposure modes – near-side, 0° full, and far-side – as shown in Table 2. Each configuration exposed the dummy to a different loading condition. Multiple tests were run in each condition to assure that the dummy was thoroughly exercised in each exposure mode. Each set of exposures represents a test with a different vehicle. For example, the three 30º Near Driver exposures represents three left 30° angle tests with three different vehicle models. Also, both THOR-50M units are respesented in each exposure set.

Additionally, the near side and far side modes were exposed to a limited number of 48 km/hr tests. At the regulatory speed of 40 km/hr, the longitudinal acceleration of a vehicle in the angled test is typically less than that of the 0º impact. The added 48 km/hr crashes allowed the THOR-50M units to be exercised more thoroughly in the 30º angled mode.

Table 2. THOR-50M test exposures (19 total tests).

Seat position, THOR-50M Exposure	Tests at 40 km/hr	Tests at 48 km/hr
30º Near Driver	3	2
0º Full Driver	4	0
30º Far Driver	2	1
30º Near Passenger	2	2
0º Full Passenger	4	0
30º Far Passenger	2	1

THOR-50M injury risk: baseline comparative values

Injury Assessment Reference Values (IARVs) typically refer to the limits for a given injury criterion calculated based on crash test results. For regulatory purposes, IARVs are defined in the regulation that describes the crash test modes, such as FMVSS No. 208. As the THOR-50M is not currently included in FMVSS No. 208, a set of baseline comparative values were selected for the purposes of the current study (Table 3).

To guide the selection of baseline values, we referred to injury criteria specific to the THOR-50M [12]. Generally, we selected reference values that represent a 50% risk of either Abbreviated Injury Scale (AIS) 2+ or 3+ injury severity, depending on the body region. When metrics were used that correspond to risk levels other than 50%, we selected values with risk levels that correspond to IARVs defined for the Hybrid III 50th percentile male in FMVSS No. 208.[1]

Table 3. THOR-50M baseline comparative reference values

Body Region	Measurement or criterion	Units	Baseline Comparative Ref.	Injury severity, risk level
Head	HIC15	none	700*	AIS 2+, 11%
	BriC	none	0.96	AIS 3+, 50%
Neck	Nij	none	0.88*	AIS 2+, 30%
Chest	3ms Clip	g	60*	Unreported
	Deflection	mm	51.4	AIS 3+, 50%
Pelvic	Acetabulum Force	N	3381	AIS 2+, 50%
Femur	Peak Compression	N	9450*	AIS 2+, 30%
Lower Leg	Revised Tibia Index	none	1.23	AIS 2+, 50%

*The reference value for THOR-50M corresponds to the same risk level as specified in FMVSS No. 208 for the HIII-50M

Test Schedule

Table 4 summarizes the schedule of testing. All crash tests were run at the same lab, Applus-Idiada-Karco. The nineteen tests were run between September 2020 and September 2021, with a four-month gap between mid-January to mid-May 2021 in which no testing was performed due to other NHTSA priorities. A NHTSA test number is denoted for each test, from which test reports, photos, videos, and instrumentation data may be found by searching within NHTSA's Crash Test Database[2]. Each report provides all test signals from the crash tests, pre- and post-test measurements of the vehicle, pre-test measurements of the occupant positions, qualification testing results performed before the crash test on each of the THOR-50M unit(s), and post-test inspection of the THOR-50M unit(s).

The one-year, nineteen-test schedule is typical of the schedule at a given test lab that supports NHTSA's regulatory and consumer information programs. For comparison purposes, consider a recent timeline NHTSA followed to support the New Car Assessment Program (NCAP). From January 2020 through September 2021, Applus-Idiada-Karco ran fourteen frontal crash tests to support NCAP. The NCAP tests were run at 56 km/hr using belted Hybrid III dummies in which a similar schedule was followed. That is, between full vehicle tests, the ATDs underwent qualification testing, partial tear-down for inspection purposes, and other handlings and delays similar to those

[1] Values reported in Table 3 have been chosen for comparative purposes only, as reported herein. Table 3 should not be interpreted as a NHTSA determination of injury assessment reference values for a future regulatory implementation of the THOR-50M.

[2] NHTSA's Vehicle Crash Test Database, https://www.nhtsa.gov/research-data/research-testing-databases#/vehicle.

experienced in the THOR-50M test series described herein. (During this time period, Applus-Idiada-Karco did not run any FMVSS No. 208 tests under NHTSA's compliance program.)

Table 4. Testing Schedule

Crash test date	Test no.	EG2595 Pre-test qualif start/stop dates	DO9799 Pre-test qualif start/stop dates
9/9/2020	v11284	n/a	7/16 - 7/23 Full[1]
9/25/2020	v11285	7/14 - 7/22 Full[1]	n/a
10/1/2020	v11286	n/a	9/15 - 9/16 Partial
10/9/2020	v11287	10/6 - 10/8 Partial	n/a
10/21/2020	v11245	n/a	10/9 - 10/12 Partial
12/7/2020	v11246	10/14 - 11/24 Full	n/a
12/15/2020	v11362	n/a	10/28 - 11/17 Full
12/18/2020	v11363	12/16 - 12/17 Partial	n/a
1/8/2021	v11361	12/23 - 1/6 Partial	12/23 - 1/5 Partial
1/15/2021	v11364	1/12 - 1/14 Partial	1/12 - 1/13 Parial[2]
----------------------------- *BREAK IN TESTING* -----------------------------			
5/21/2021	v11630	5/13 - 5/19 Full	n/a
6/7/2021	v11637	5/28 - 6/1 Partial	n/a
6/24/2021	v11629	6/14 - 6/15 Partial	n/a
7/2/2021	v11628	6/30 - 6/30 Partial	n/a
7/30/2021	v11635	7/12 - 7/29 Partial	n/a
8/13/2021	v11636	8/12 - 8/12 Partial	n/a
9/17/2021	v11639	8/20 - 8/26 Partial	6/24 - 7/22 Partial[1]
9/22/2021	v11665	no pre-test qualif	no pre-test qualif
9/24/2021	v11638	10/11 - 10/21 Full[3]	10/12 - 10/20 Full[3]

[1] Qualification tests performed by NHTSA at DML

[2] DO9799 temporarily returned to DML for other NHTSA purposes.

[3] Post-test qualifications performed after test v11638.

RESULTS

Qualification tests

Throughout the test series, there were six sets of full qualification tests carried out, and fifteen partial sets. In all but one instance, every qualification target was met. The one instance occurred with the neck of DO9799. After a break in testing from January-May 2021 (during which time NHTSA employed DO9799 for other research investigations), the dummy was shipped back to Applus-Idiada-Karco without a fully qualified neck. Specifically, neck axial force in the neck extension test was slightly above the target. Nonetheless, we proceeded with the final two vehicle tests with the neck because we had no qualified spares to swap into the dummy.

Aside from loose cables and connectors on instrumentation on the non-DAS unit, DO9799 (discussed in the next section), neither of the two units had any parts replaced. Only routine adjustments were needed in order to meet all the qualification criteria during crash testing.

Moreover, post-test qualifications performed at Applus-Ididia-Karco were consistent with the pre-test qualifications performed at NHTSA's DML. That is, all tests met the qualification requirements with the exception of neck axial force in the extension test. There were no instances in which either of the THOR-50M units fell out of compliance after being subjected to any of the nineteen crash tests, despite being subjected to fairly high crash forces (as judged by proximity to injury references seen later on in Figs. 6 and 7). Even in the one instance in which the qualification target was not met (axial force in the neck extension test on DO9799), the Applus-Ididia-Karco result was very consistent with the DML: the axial force was over the 3210 N limit by about 200 N at both labs.

In summary, the qualification schedule followed in this series is typical of how an ATD is used in NHTSA's FMVSS compliance program. That is, between qualifications, the ATD undergoes a full vehicle test, partial tear-down for inspection purposes, and other handlings and delays.

Seating procedure

The THOR-50M seating procedure, cited earlier, was followed in all tests. There were tests with four different vehicles and two seating positions. Among the tests, a 2020 Honda Accord was used more often than the other three models. For the Accord tests, there were five in which a THOR-50M unit was seated in the driver seat. Below is a diagram derived from the Accord vehicle reports that indicates the relative uniformity of the dummy positioning. It shows the x- and z- coordinates relative to the door lock striker on the driver side of the vehicle. Coordinates of high interest are shown in the figure, including the outboard H-point. Both of the THOR-50M units are represented in this figure: three with EG2595, two with DO9799.

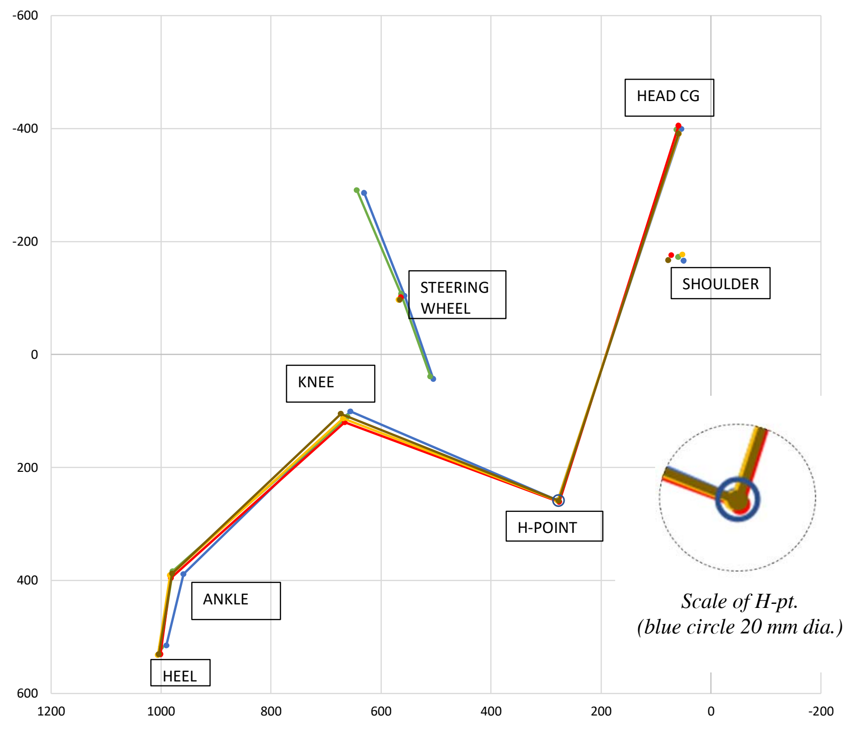

Figure 2. THOR-50M Driver: Seated coordinates in five Honda Accord tests

For comparative purposes, a circle with a diameter of 20 mm is drawn around the average H-point, and shows that all H-points are enclosed by the circle. This corresponds to the positioning requirement for the THOR-50M (and

HIII-50M as specified in FMVSS No. 208) wherein the H-point of the dummy must lie within +/- 10 mm of the H-point determined by the SAE J826 manikin in the x- and z-directions. Other measurements, such as pelvis angle and tilt sensor readings were all within the target tolerances specified by the seating procedure.

The steering wheel is provided as a reference on the relative variability seen from one vehicle to another, independent of any variability associated with THOR-50M units. Other sources of variability among the five THOR-50M positioning observations included the seat back angle (varied by 2º), head restraint post angle (also varied by 2º), and seat track position (varied by 10 mm).

Temperature control.

According to NHTSA's Qualification Procedures, the temperature of the dummy must be soaked in a controlled environment that is 20.5º to 22.2º C (69º to 72º F) and has a relative humidity from 10 to 70% for at least 4 hours prior to a test. This requirement has been put in place because the dummy response is temperature dependent. The damping material that covers the ribs is particularly sensitive to temperature.

For the DAS-equipped unit, EG2595, the heat generated by the DAS battery pack will warm the internal ribs once it is switched "ON." During full-dummy qualification testing, an added step was taken to assure that the actual rib surface temperature was between 20.6º to 22.2º C at the time of the pendulum impacts. This was accomplished by applying a thermocouple to monitor the temperature of rib number 2 while using a portable fume extractor[3] to maintain the temperature range. This device provides air movement, forcing the hot air out of the ATD via a suction hose that is easily inserted into the jacket. Subsequently, cool ambient air is pulled through existing openings in the jacket around the neck and arms, over the spine box, DAS battery pack, and thorax ribs.

For FMVSS No. 208 crash testing, the ATD soak requirement is also 20.5º to 22.2º C . In tests with the EG2595, we were routinely able to maintain this range without the need for a fume extractor by limiting the "ON" time of the DAS unit. The thermocouple remained in place on rib number 2 to ensure that temperature was maintained at 20.5º to 22.2º C at the time of the crash.

There were, however, exceptions in which the rib temperature was slightly elevated at the time of the crash. One such test occurred on September 24, 2021 (Figure 3). This was the very last test in the entire test series. Both THOR-50M units were seated in the vehicle: EG2595 (with the internal DAS) and DO9799 (no internal DAS). The rib temperature of DO9799 may be treated as a benchmark. At approximately 0740 hours, DO9799 was removed from the dummy calibration lab, which was set to a slightly lower temperature, and brought into the vehicle bay. EG2595, on the other hand, had been brought into the vehicle bay the day before.

For EG2595, the rib temperature at the time of the crash was over the limit by 0.1 degrees C. Two factors contributed to this: 1) a slightly longer than usual time lapse between the final switching "ON" of the DAS unit (just over 30 minutes); and 2) the outside air temperature. At the lab where the tests occurred (Applus Idiada Karco), bay doors to the lab are opened just prior to the test, the vehicle is released, and the actual crash occurs outdoors. During this test, the slightly longer than usual delay between the bay door opening and the barrier impact allowed the hot outside air temperature (32.8º C, 91º F) to warm the dummy.

This exercise demonstrates the need for diligence on maintaining the temperature when using any DAS-equipped dummy. It is not a situation that is unique to the THOR-50M. In another recent NHTSA test series using the WorldSID-50M dummy (which also has an internal DAS) [13], we used the fume extractor during the immediate pre-crash exercises to ensure that the rib temperatures are maintained within the specified range.

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[3] Weller Tools, https://www.weller-tools.com.

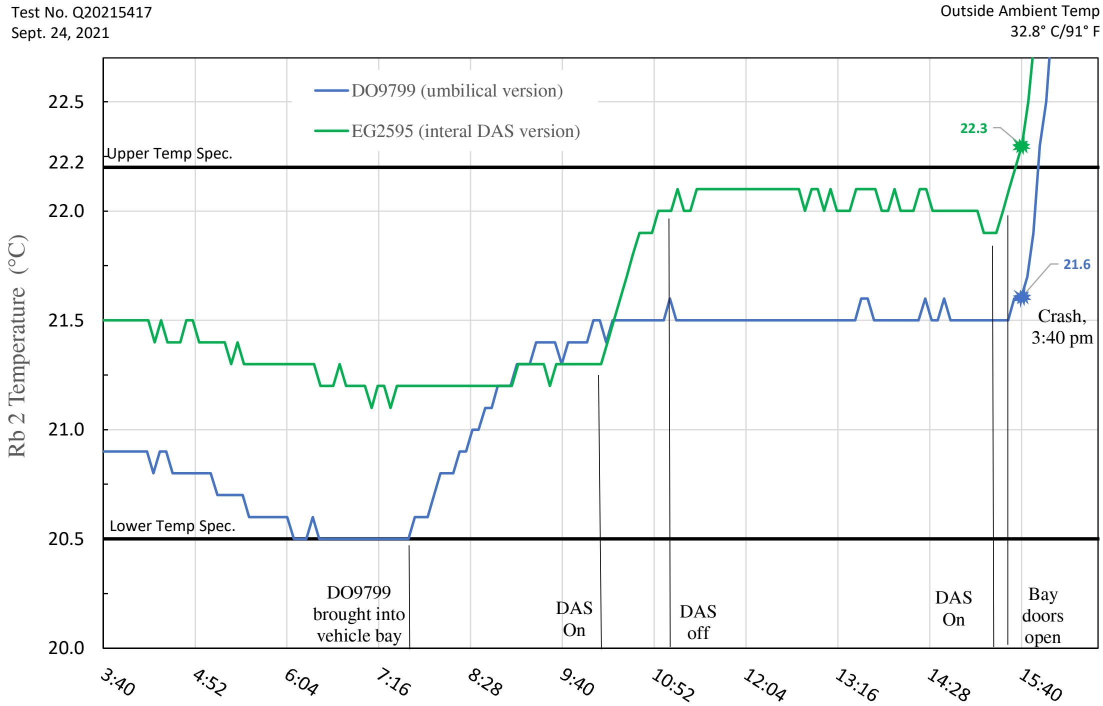

Figure 3. THOR-50M Rib No. 2 Temperature Timeline Prior to Crash Test v11638.

Crash Tests - General rigor

To assess the degree to which the THOR-50M units were exposed to a harsh testing environment, we examined various dummy metrics. Figures 4 and 5 indicate the proximity to baseline comparative values (Table 3) for the driver and passenger exposures, respectively. The colors in the plots indicate the ratio of the respective THOR-50M metric to the comparative value:

Dark green:	<= 40%
Light green:	> 40 and <= 60%
Yellow:	> 60 and <= 80%
Brown:	> 80 and <= 100%
Red:	> 100%

For example, in Figure 4 there were five crashes for 30º near-side driver exposures, three at 40 km/hr (involving an Accord, a CX-5, and an Equinox), two at 48 km/hr (involving a CX-5 and an Accord). Two of the 40 km/hr crashes produced a BrIC score between 80-100% (brown) of the baseline reference of 0.96. The other crash was between 60-80% (yellow), as were the two 48 km/hr tests.

Figures 4 and 5 help show the degree to which the various body regions of the dummy were exposed to injurious conditions. In the majority of crash configurations, each body region had at least one high-risk exposure for both the driver and passenger positions. Nonetheless, neither of the THOR-50M units sustained damage, with the exception of sensor connector and cable problems in DO9799. Notably, the DAS unit, EG2595, did not sustain any connector or cable breaks.

In summary, the crash test series demonstrated how the dummy stood up to the rigors of crash testing. Additionally, the following observations were made:

* The 30º near-side crashes were generally more injurious for neck injuries.

* The 48 km/hr tests were more rigorous for all injury metrics and for all crash configurations.

* The Head Injury Criterion (HIC) has comparatively low injury values for all conditions.

* Abdominal deflections were universally low and are not included in Figs. 4 and 5 (all well below 63 mm, which corresponds to 10% risk of AIS 3+ injury). This was not surprising, as there was no lap belt loading to the abdomen in these unbelted tests, and the frontal airbags distributed the restraint force over the entire torso.

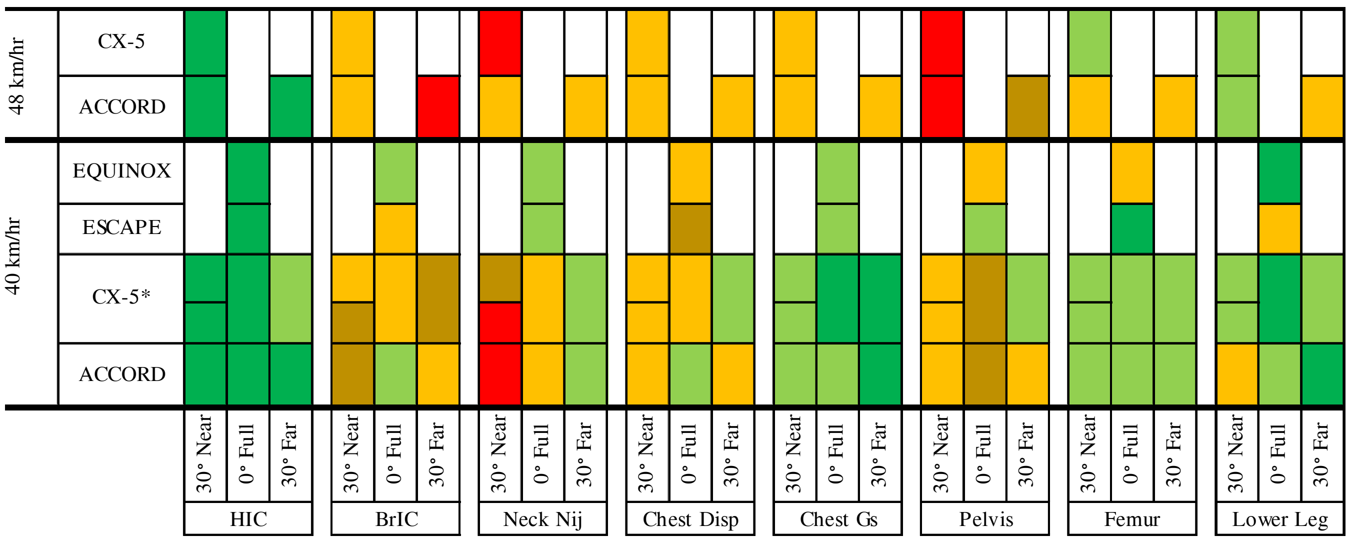

Figure 4. THOR-50M Driver: Comparitive injury metrics by exposure.
(*CX-5 was used in two duplicate 30° near side crash tests.)

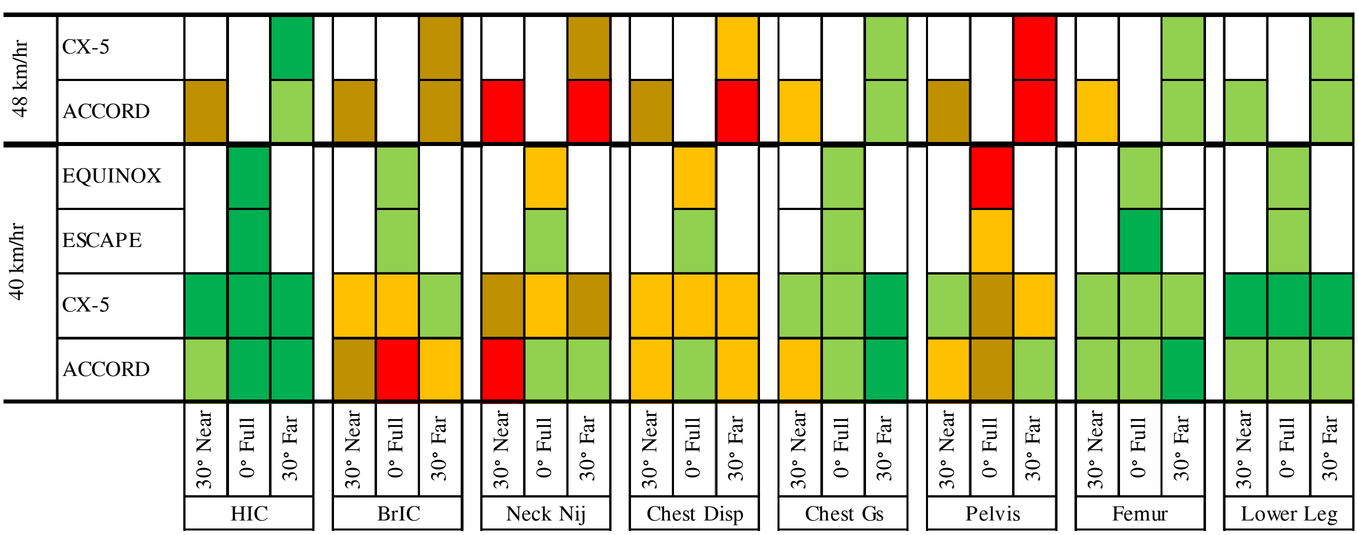

Figure 5. THOR-50M Passenger: Comparitive injury metrics by exposure.

Note: In Figs. 4 and 5, for Pelvis, Femur, and Lower Leg, the maximum of the right and left measurement is represented in the charts. Additionally, for Lower Leg, the maximum of the upper and lower tibia index is represented.

Dummy kinematics

NHTSA had not previously exercised the THOR-50M in unbelted vehicle crash tests, and in this series we observed body motions that were not seen in the previous studies cited in the Introduction. The most noteworthy observation occurred in several cases where vaulting over the airbag caused head contact with the windshield and header. An example of this occurred in test v11287 on the passenger side head of a right 30° angled (near side), 48 km/hr crash test with EG2595. The contact is shown in Figure 6. This resulted in fairly high compressive loads in the upper neck load cell (4808 N), which yielded an Nij value of 1.56 (red bar in Fig. 5) in the compression-extension mode. Additionally, HIC15 (629) and BrIC (0.84) were elevated (brown bars in Fig. 5). This was the worst-case test for passenger-side compressive neck loading, though other tests showed similar dummy kinematics for both the driver and the passenger. Nonetheless, the post-test inspection of the dummy revealed no unusual damage. Subsequently, the dummy underwent a full series of qualification tests; all qualification targets were attained without issue.

Figure 6. Passenger-side head impact with the windshield in test v11287, right 30° angled (near side), 48 km/hr.

Dummy inspections

The two THOR-50M ATDs were inspected throughout the test series. Other than instrumentation, no parts were found to have become damaged and in need of replacement. Aside from minor wear and tear such as head skin abrasions, there was no damage to either THOR-50M unit. Sensor anomalies and damage to the THOR-50M ATDs are summarized in the Appendix. Note that some instrumentation (for example, the right acetabulum X-axis force channel) was not functioning prior to the beginning of this test series.

DISCUSSION

Availability of replacement parts

The test series served as a "dry run" for the THOR-50M as it would be used in a regulatory environment using two serialized dummies, EG2595 and DO9799. During the test series, there were no part replacements in either of the units. However, this is not necessarily how the dummy will be used. NHTSA treats each of our THOR-50M units not so much as a serialized dummy, but as a set of serialized parts and sub-assemblies that are disassembled and reassembled at regular intervals. These sub-assemblies undergo routine maintenance on separate schedules, unlike what was done in the test series described herein.

When a THOR-50M unit is returned to NHTSA's DML after testing, it undergoes a routine breakdown and inspection. When the dummy is reassembled, a different set of parts may be introduced. Pre-qualified sub-assemblies may also be introduced. For example, a head and neck assembly may be taken out of service at regular intervals and set aside to await preventative maintenance. At a later time, a full inspection and re-qualification takes place. This process may or may not include the replacement of bumpers (also serialized), cables, or other components. However, it takes place under a separate schedule. Once cleared for use, the sub-assembly may end up in another serialized dummy. Thus, a serialized dummy does not typically define the dummy well because different parts are constantly being swapped in and out in regular intervals.

However, for the test series described herein, there were no spare parts or sub-assemblies available, so there were no part swaps. For this reason, EG2595 was delivered by the DML to Applus-Idiada-Karco – and the entire tests series was run – without a fully functioning acetabulum load cell (right X-force was not operating) and with a non-functioning occipital condyle potentiometer. Also, during a break in testing from January-May 2021, NHTSA employed DO9799 for other research investigations. When the dummy was being prepared for shipment back to Applus-Idiada-Karco, the DML discovered that the neck did not fully pass the qualification tests. We knowingly proceeded with the final two vehicles tests with the neck because we had no qualified spares to swap into the dummy.

Once the THOR-50M design is adopted in 49 CFR Part 572 and the dummy begins use in FMVSS compliance testing, an investment by NHTSA into an inventory of dummies with a full supply of spare parts may become a higher priority.

Qualification frequency

For the same reasons as stated above, we chose to run the full set of qualification tests on the THOR-50M after each crash test. This was confirmed midway through the series by a second set of full qualification tests. This, however, did not compromise the crash test results, as all qualification targets were met, with the exception of the neck tension on DO9799 in the neck extension test (upon return from the DML, as noted earlier). Nonetheless, in our future regulatory program, NHTSA may exercise added vigilance and opt to run a full set of qualification tests before every crash test. If crash tests are scheduled within a few days (with both tests preceded by a full set of qualification tests), sub-assembly swaps (or swapping out of the complete dummy) may be needed.

It is also notable that Applus-Idiada-Karco did not have substantial experience with THOR-50M qualification testing before this test series. They were ***not*** one of the laboratories included in the original lab-to-lab qualification testing used to develop the qualification specifications. Additionally, EG2595, a relatively new unit, was not included in the original ATD-to-ATD or lab-to-lab qualification test series. Thus, Applus-Idiada-Karco's experience has provided NHTSA with additional evidence that the qualification tests are reproducible and that NHTSA’s THOR-50M design specifications have produced highly uniform and durable units.

Channel counts

During the test series describe herein, both dummies were fully instrumented with over 130 channels, including 40 channels in the lower legs alone. For future regulatory use, the channel count will likely be reduced. Many of the signal problems identified during this test series would probably be among channels that would be omitted from regulatory use: accelerometers on the pelvis, tibia shaft, and anterior superior iliac spine; femur moment channels. Thus, the time we devoted to repairing or replacing these instruments would not be experienced in future regulatory testing. NHTSA also recorded other data during this test series that are not typically gathered in regulatory tests. These include toepan intrusion measurements and 6-axis vehicle vs dummy measurements that are needed to track head kinematics.

Vehicle assessment

With regard to vehicle safety and how the four vehicle models compare with one another, no firm conclusions can be drawn due to the small sample size and the lack of repeat tests under identical conditions. Injury metrics are reported herein in order to demonstrate that the THOR-50M was exoposed to rigorous testing, not to evaluate or compare the safety of the vehicles tested.

LIMITATIONS

A limitation of this study was that only four vehicle models were tested and all tests were run at a single lab. The usability experience at other labs may vary. It may also vary with other vehicle models.

CONCLUSIONS

In a series of 19 FMVSS No. 208 unbelted frontal rigid barrier crash tests, two THOR-50M units were implemented and successfully completed the test series. Scripted procedures for dummy assembly, qualification, and handling were followed without issue, and the seating procedures resulted in highly uniform positioning. Sensor anomalies observed over the course of testing were consistent with those common in dummies already in Part 572. Aside from minor abrasions on the head skin of one of the units, there were no broken parts or part replacements throughout testing. Based on the experiences of this testing series, the THOR-50M appears fit for use in standardized testing.

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APPENDIX

Table A-1. Summary information of unbelted tests series

Test Date	Make and Model	Crash Config	Speed (km/hr)	Driver	RF Pass	Test No.
9/9/2020	2020 Honda Accord	30° L	48	DO9799	*HIII-50M*	v11284
9/25/2020	2020 Honda Accord	30° R	48	EG2595	*HIII-50M*	v11285
10/1/2020	2020 Honda Accord	30° L	48	*HIII-50M*	DO9799	v11286
10/9/2020	2020 Honda Accord	30° R	48	*HIII-50M*	EG2595	v11287
10/21/2020	2020 Mazda CX-5	30° L	48	DO9799	*HIII-50M*	v11345
12/7/2020	2020 Mazda CX-5	30° R	40	EG2595	*HIII-50M*	v11346
12/15/2020	2020 Mazda CX-5	30° L	48	*HIII-50M*	DO9799	v11362
12/18/2020	2020 Mazda CX-5	30° R	40	*HIII-50M*	EG2595	v11363
1/8/2021	2020 Honda Accord	0°	40	DO9799	EG2595	v11361
1/15/2021	2020 Mazda CX-5	0°	40	DO9799	EG2595	v11364
5/21/2021	2020 Mazda CX-5	30° L	40	EG2595	*HIII-50M*	v11630
6/7/2021	2020 Mazda CX-5	30° L	40	*HIII-50M*	EG2595	v11637
6/24/2021	2020 Honda Accord	30° L	40	EG2595	*HIII-50M*	v11629
7/2/2021	2020 Honda Accord	30° R	40	EG2595	*HIII-50M*	v11628
7/30/2021	2020 Honda Accord	30° L	40	*HIII-50M*	EG2595	v11635
8/13/2021	2020 Honda Accord	30° R	40	*HIII-50M*	EG2595	v11636
9/17/2021	2021 Chevrolet Equinox	0°	40	EG2595	DO9799	v11639
9/22/2021	2021 Ford Escape	0°	40	EG2595	DO9799	v11665
9/24/2021	2020 Mazda CX-5	30° L	40	DO9799	EG2595	v11638

Table A-2. EG2595 inspection: instrumentation anomalies and damage

Date	Test No.	Sensor Anomaly	Description	Repaired
9/25/2020 *Before 1st test*	v11285	Acetabulum LC, Right, X-force	The channel was found to be inoperable upon receipt of the dummy from the DML. Cause of malfunction was unknown. A replacement load cell was not available and a timely repair was not feasible. All crash testing conducted without this signal.	NA
		Occipital Condyle, Rotary Potentiometer	Dummy arrived from DML with OC unwired. A special connector needed for the SLICE6 system was not readily available. All crash testing conducted without this signal.	NA

Table A-3. DO9799 inspection: instrumentation anomalies and damage

Date	Test No.	Sensor Anomaly	Description	Repaired
9/9/2020 *1st test*	v11284	Tibia, Left, Mid-shaft, X-acceleration	The channel was found to be inoperable upon receipt of the dummy from the DML. Cable damage at accelerometer was found, too close to accelerometer to fix. All crash testing conducted without this signal.	No
		Tears in face foam	THOR-50M was delivered by DML with tears in the face foam. All face qualification tests passed nonetheless. All crash testing conducted with foam in this condition.	No
		Abdomen, Right, DGIR, X-displacement	This channel recorded an intermittent signal. The cause was undetermined. The intermittent signal did not occur in the rest of the qualification and vehicle testing.	NA
		Upper Chest, Left, DGIR, Z-rotation	No data recorded due to damage to cable despite operability during qualification and pre-test polarity checks. It was determined that a wire was damaged. Cause of damage was unknown; may have occurred pre-test since there was no data at time t=0. The wire was repaired after the test.	Yes
10/1/2020 *2nd test*	v11286	Scrapes on top of head skin	Abrasions to head covering were presumed to have occurred during testing.	No
		Femur, Left, Y-moment	No data recorded due to damage to cable despite operability during pre-test polarity checks. Cause of damage was unknown; may have occurred pre-test. The wire was repaired after the test.	Yes
		Tibia, Right, Mid-shaft, X-acceleration	No data recorded due to damage to cable despite operability during pre-test polarity checks. Cause of damage was unknown; may have occurred pre-test since there was no data at time t=0. The wire was repaired after the test.	Yes
12/15/2020 *4th test*	v11362	T1, X-acceleration	Intermittent signal recorded. Cause was not readily obvious. Continued testing without further investigation.	NA
		Pelvis, Z-acceleration	No data recorded due to damage to cable despite operability during pre-test polarity checks. Cause of damage was unknown; may have occurred pre-test since there was no data at time t=0. The wire was repaired after the test.	Yes
9/22/2021 *8th test*	v11665	A.S.I.S., Left, Y-Moment	The channel failed during the crash tests, with an intermittent signal due to a broken cable. The connector was resoldered to repair.	Yes
		Femur, Right, Z-moment	The channel failed during the crash tests when the signal dropped off due to a broken cable. The connector was resoldered to repair.	Yes
		Upper Tibia, Left, X-Force	Sensor failed between 68.3 to 76.9 ms. Channel was inspected; cause of the failure is unknown. Channel was retested without issue. Continued testing without further investigation.	NA
9/24/2021 *9th (last) test*	v11638	A.S.I.S., Left, Y-Moment	No data recorded despite operability during pre-test polarity checks. Cable problem found in post-test inspection; cause of damage was unknown; may have occurred pre-test since there was no data at time t=0. The wire was repaired after the test.	Yes
		Acetabulum, Right Y-Force.	The channel failed at 78 ms during the last crash test.	Yes
		Femur, Right, Y-Force	No data recorded despite operability during pre-test polarity checks. Cause of damage was unknown; may have occurred pre-test since there was no data at time t=0. The wire was repaired after the test.	Yes