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Fixed Workstation Tables in Passenger Railcars

Abstract: This rail standard specifies minimum strength and crashworthiness requirements for fixed workstation tables installed in passenger railcars that are part of the general railroad system of transportation.

Keywords: anthropomorphic test device (ATD), crashworthiness, fixed workstation tables, injury criteria, passenger rail, safety

Summary: In passenger rail seating configurations with fixed workstation tables, there is a risk of serious thoracic and abdominal injury when passengers impact a table during a rail accident. Tables designed to absorb energy and limit contact forces can significantly reduce the risk of injury. Additionally, tables positioned between facing rows of seats can compartmentalize occupants during a collision, which can limit an occupant's secondary impact velocity and prevent tertiary impacts with other objects or passengers.

Scope and purpose: This safety standard applies to new railcar procurements and is intended to provide guidance for the design and testing of fixed workstation tables used in passenger railcars. This standard applies to fixed workstation tables that are positioned at revenue seats in any type of passenger car. It does not apply to fold-down seat back tables, tables in café and dining cars, or tables in sleeping car rooms. Portions of this standard are intended to provide details on how to demonstrate compliance with the requirements of 49 CFR Part 238.233, "Interior fittings and surfaces." The purpose of this standard is to establish minimum strength requirements for tables, to establish minimum human injury criteria requirements, and to define the test conditions and associated performance requirements for dynamic and quasi-static table testing.

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Participants

The American Public Transportation Association greatly appreciates the contributions of the **PRESS Construction & Structural Working Group**, which provided the primary effort in the drafting of this document.

At the time Rev. 2 was completed, the working group included the following members:

Frank Maldari, MTA Long Island Rail Road, *Chair*
Mehrdad Samani, LTK Engineering Services, *Vice Chair*
Martin Young, Sound Transit, *Secretary*

Gabriel Amar, *Systra Canada*
Enrique Arroyo-Rico, *Alstom*
Danny Bailey, *DCTA*
Evelyne Berthomme, *Alstom*
Shafal Bhushan, *Baker Bellfield*
Martin Bigras, *Bombardier Transportation*
Robert Bocchieri, *ARA*
Michael Burshtin, *Amtrak*
Paul Callaghan, *Transport Canada*
Gordon Campbell, *Crosslinx Transit Solutions*
Luiz Cano Fernandez, *Alstom*
Bruce Cardon, *UTA*
Michael Carolan, *Volpe*
Mike Cook, *LTK*
Robert Cook, *SCRRA*
Joshua Coran, *Talgo Inc.*
Sean Cronin, *Metra*
Richard Curtis, *Curtis Engineering Consulting*
Felipe Czank, *Alstom*
Nathaniel Eckman, *LTK*
Shaun Eshraghi, *Volpe*
Steve Finegan, *Atkins*
Christian Forstner, *Seisenbacher Rail Interiors*
Tom Freeman, *International Name Plate Supplies*
Andre Gagne, *Bombardier Transportation*
Gene Germaine, *Kustom Seating Unlimited*
Michael Gill, *Atkins*
Garrett Goll, *Voith Turbo*
Robert Gonzales, *MRCOG*
Jeffrey Gordon, *FRA*
Travis Gorhum, *TTCI*
Glenn Gough, *Siemens Mobility*
Yosi Grunberg, *Atkins*
Dong Keun Ha, *SCRRA*
Dongni Han, *CRRC MA*
Nicholas Harris, *LTK*
Jason Hesse, *STV Incorporated*
Ritch Hollingsworth, Hatch/*LTK*
Karina Jacobsen, *Volpe*
Paul Jamieson, *retired*
Robert Jones, *Stadler Rheintal AG*
Micheal Kelsey, *North County Transit District*
Larry Kelterborn, *LDK Advisory*
Joseph Kenas, *Bombardier Transportation*
Steven Kirkpatrick, *ARA*
Peter Lapre, *FRA*
Paul Larouche, *Bombardier Transportation*
Dominique Le Coree, *Alstom*
Ana Maria Leyton, *Transport Canada*
Patricia Llana, *Volpe*
William Luebke, *Kustom Seating Unlimited*
Francesco Maldari, *MTA Long Island Rail Road*
Eloy Martinez, *LTK*
Ronald Mayville, *SGH*
Patrick McCunney, *Atkins*
James Michel, *Marsh*
Tomoyuki Minami, *Central Japan Railway*
Travis Nelson, *LTK*
Juergen Neudorfsky, *Seisenbacher Rail Interiors*
Steve Orzech, *Freedman Seating Company*
Chase Patterson, *Voith Turbo*
Thomas Peacock, *Atkins*
Gary Petersen, *TransLink*
Anand Prabhakaran, *Sharma* & *Associates*
Przemyslaw Rakoczy, *TTCI*
Denis Robillard, *Baultar*

Steven Roman, *LTK*
Thomas Rutkowski, *Virgin Trains*
Mehrdad Samani, *LTK*
Brian Schmidt, *San Joaquin Regional Rail*
Gerhard Schmidt, *Siemens Mobility*
Martin Schroeder, *Jacobs*
Frederic Setan, *Alstom*
Kristine Severson, *Volpe*
Melissa Shurland, *FRA*
Nick Sorensen, *UTA*
Benjamin Spears, *LTK*
Jeremy Spilde, *Metro Transit*
Laura Sullivan, *Volpe*
Lukasz Szymsiak, *VIA Rail*
Michael Trosino, *Amtrak*
Rudy Vazquez, *Amtrak*
Doug Warner, *Herzog Transit Services*
Clifford Woodbury, *LTK*
Leonard Woolgar, *Baultar*
Martin Young, *Sound Transit*
Theresa Zemelman, *Raul V. Bravo + Associates*
Steven Zuiderveen, *FRA*

Project team
Narayana Sundaram, *American Public Transportation Association*
Nathan Leventon, *American Public Transportation Association*

Introduction

This introduction is not part of APTA PR-CS-S-018-13, Rev. 2, "Fixed Workstation Tables in Passenger Railcars."

This standard applies to all:

1. Railroads that operate intercity or commuter passenger train service on the general railroad system of transportation; and
2. Railroads that provide commuter or other short-haul rail passenger train service in a metropolitan or suburban area, including public authorities operating passenger train service.

This standard does not apply to:

1. Rapid transit operations in an urban area that are not connected to the general railroad system of transportation;
2. Tourist, scenic, historic, or excursion operations, whether on or off the general railroad system of transportation;
3. Operation of private cars, including business/office cars and circus trains; or
4. Railroads that operate only on track inside an installation that is not part of the general railroad system of transportation.

Fixed Workstation Tables in Passenger Railcars

1. Applicability

In passenger rail seating configurations with fixed workstation tables, there is a risk of serious thoracic and abdominal injury when passengers impact a table during a rail accident [1, 2, 3]. Tables designed to absorb energy and limit contact forces can significantly reduce the risk of injury. Additionally, tables positioned between facing rows of passenger seats can compartmentalize occupants during a collision, which can limit secondary impact velocity and prevent tertiary impacts with other objects or passengers.

This standard defines crashworthiness requirements for fixed workstation tables installed in passenger railcars that are part of the general railroad system of transportation. This standard applies to fixed workstation tables that are positioned at revenue seats in any type of passenger car. It does not apply to fold-down seat back tables, tables in cafe and dining cars, and tables in sleeping car rooms. This safety standard applies to the procurement of workstation tables for new passenger railcars and describes the tests and table performance requirements necessary to demonstrate compliance with this standard.

The requirements in this standard are derived in part from federal regulations and industry standards. These requirements are contained in the Code of Federal Regulations (CFR) Title 49, Part 238, Section 233; American Public Transportation Association APTA PR-CS-S-016; and the United Kingdom Railway Group Standard GM/RT2100. Maximum allowable injury criteria values are derived from CFR Title 49, Part 571, Section 208; GM/RT 2100 [4]; research results sponsored by the National Highway Traffic Safety Administration (NHTSA) [5, 6, 7]; and research results sponsored by the Federal Railroad Administration (FRA) Office of Research, Development and Technology [8, 9].

2. Table attachment requirements

2.1 Attachment strength

A workstation table is considered to be an interior fitting and is subject to the attachment strength requirements in CFR Title 49, Part 238, Section 233, paragraph (c). This section is intended to provide additional guidance in satisfying these CFR requirements.

CFR Title 49, Part 238, Section 233 paragraph (c) specifies the following:

> Other interior fittings within a passenger car shall be attached to the carbody with sufficient strength to withstand the following individually applied accelerations acting on the mass of the fitting:
>
> - Longitudinal: 8g
> - Vertical: 4g
> - Lateral: 4g

The loads in paragraph (c) of Section 233 may be applied quasi-statically or dynamically. If the load is applied dynamically, then the acceleration time history shall have a duration of 250 ms and a peak of 4g in the lateral and vertical direction, and 8g in the longitudinal direction, with the peak occurring at 125 ms; an example of the 8g crash pulse is shown in **Figure 3**.

2.2 Mounting hardware

The hardware used to attach the table to the carbody shall conform to CFR Title 49, Part 238, Section 233(d): "To the extent possible, all hardware attaching interior fittings in a passenger car, except seats, shall be recessed or flush-mounted."

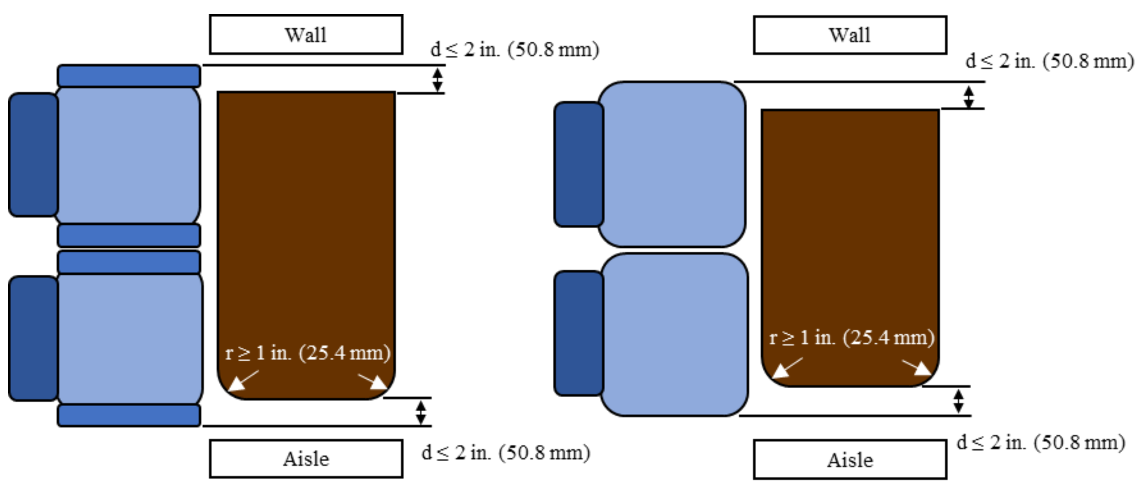
3. Table geometry requirements

The table design shall minimize points of entrapment and concentrated loading points (associated with sharp radii) with which a passenger may come into contact during a rail vehicle accident. The table shall compartmentalize occupant(s) between the occupied seat(s) and the table in the event of an accident.

The aisle-side corners of the table edge shall be rounded to a minimum radius of 1 in. (25.4 mm) (see **Figure 1**). The edges of the table's upper and lower surfaces shall be rounded to a minimum radius of 3⁄16 in. (47.6 mm) around the entire perimeter. Laterally, the gap between the table and the outside edge of the arm rests (or seat base if no arm rests are present) shall be no greater than 2 in. (50.8 mm) as depicted in **Figure 1**. While **Figure 1** depicts tables at two-passenger seats, the same geometry requirements apply to tables located at one-passenger and three-passenger seats, or tables installed between any combination of seats on either side. In all cases, the table must extend to within 2 in. (50.8 mm) from the inboard edge of the wider seating configuration; e.g., if a table is installed between single-passenger and double passenger seats then it shall comply with the geometry requirements for the double-passenger seats. A tapered tabletop, i.e., one in which the tabletop has a trapezoidal shape, is permissible if it complies with all the requirements in this standard.

The edge of the tabletop that would be impacted by a passenger must be at least 2.0 in. (50.8 mm) thick, including the radii (up to 3/16 in.) This requirement is intended to minimize concentrated abdominal loads in the event of a collision. The thickness of tabletop extensions should be at least 2.0 in. (50.8 mm) thick if the longitudinal force to stow the extensions is greater than 25 lbf (111 N).

FIGURE 1
Table Geometry Requirements, Top View



4. Operational testing

The objective of operational testing is to demonstrate that operational loads do not cause damage to the table that would prevent it from functioning as intended in a collision.

The table and its support structure shall be designed and tested to meet the individually applied quasi-static load requirements given below with minimal permanent yielding of structural materials (limits specified herein), loss of function, or change in appearance of the table or support structure. Prior to static testing, it is permissible to apply and remove up to a 100% preload to relieve any manufacturing pre-stresses that may be present. A small amount of permanent deformation measured post-test (less than 0.125 in. [3.2 mm]) shall be permissible. Single, double and triple tables shall all be tested. Both first-class and coach-class tables shall be tested unless the tables are identical.

The table shall be mounted on a rigid test fixture or simulated car structure using the same fasteners or attachment mechanism used in service—bolts, screws, seat track, tapping plate, etc. The tabletop shall not experience permanent deformation greater than 0.125 in. (3.2 mm) under the following individually applied loads:

a) Minimum 225 lbf (1000 N) load applied on a 5 × 5 in. ± 0.25 in. (127 × 127 mm ± 6.4 mm) area in a vertical downward direction at a location on the top of the table that represents the worst-case loading condition, generally at a point farthest from the table support structure. The load shall be applied for a minimum of 5 s.
b) Minimum 337 lbf (1500 N) load applied in a longitudinal (with respect to the carbody) direction on an 8 in. ± 0.25 in. (203.2 mm ± 6.4 mm) length across the full thickness of the tabletop at a location on the table edge facing the passenger that represents the worst-case condition, generally at a point farthest from the table support structure. The load shall be applied for a minimum of 5 s.

The operational loads specified above do not need to be applied to deployable tabletop extensions, if used.

5. Crashworthiness testing

The objectives of crashworthiness testing are to demonstrate the following:

- The table effectively absorbs kinetic energy while limiting forces acting on the occupants.
- The table remains attached to the test sled or fixture.
- The table effectively compartmentalizes the ATDs.
- The table effectively limits human injury of the head, chest, neck, abdomen and femurs.
- Table deformation does not expose sharp or pointed objects that may seriously injure an occupant, or spaces capable of entrapping an occupant during a rail accident.

Single, double and triple tables shall all be tested. Both first-class and coach-class tables shall be tested, unless the tables are identical. In this case, the configuration with the largest longitudinal distance (dimension *A* in **Figure 4**) between the seat and table shall be tested.

Two options are provided to demonstrate that a particular table design complies with these crashworthiness objectives. The test(s) shall be conducted in accordance with the requirements given in Section 5.1 for Option A or Section 5.2 for Option B.

If multiple seat configurations are used in a procurement with a structurally identical table design, then a “critical set” of test configurations may be identified that are most likely to:

1. cause human injury;
2. impinge on rear-facing survival or egress space;
3. fail to compartmentalize occupants; and
4. cause failure of carbody attachments.

At the discretion of the purchaser, the configurations in the “critical set” may be tested as the worst case for a particular table design, rather than testing every configuration. For example, if a table is used in multiple seating configurations that differ only in seat pitch, then a single dynamic test may be performed to represent all the seat pitches by conducting the test with the largest seat pitch. The survival space requirement should be evaluated using a theoretical rear-facing seat position based on the smallest seat pitch configuration. This combination of testing with the largest seat pitch while evaluating survival space with the theoretical smallest seat pitch would represent the worst-case situation for injury and compartmentalization of forward-facing occupants and survival space conditions for rear-facing occupants.

If a structurally identical table design installed in a similar configuration has already been tested in accordance with the requirements of this standard, then at the discretion of the purchaser, and in lieu of additional testing, the manufacturer may provide prior test data in accordance with Section 6 of this document to demonstrate that the table is in compliance with the requirements of this standard.

5.1 Option A: Dynamic sled test with H3-RS or THOR-50M ATD

A dynamic sled test shall be conducted in accordance with the conditions given in Section 5.1.1. The required test measurements and documentation are given in Section 5.1.2. The workstation table shall comply with all the performance requirements listed in Section 5.1.3.

5.1.1 Dynamic sled test conditions

A workstation table shall be mounted to a simulated car structure representative of the intended installation using the same flooring material and the same fasteners or attachment mechanism intended for use in service—bolts, screws, track, tapping plate, etc.

A passenger seat (or seats) shall be mounted to the simulated car structure at the nominal location relative to the table for the intended rail service. A facing seat (or seats) shall be mounted to the simulated car structure on the opposite side of the table, at the nominal seat pitch of the intended installation. Instrumented ATDs representative of 50th percentile adult males shall be positioned to face the direction of travel, such that all seats facing the direction of travel are simultaneously occupied by ATDs.

At least one ATD shall be an H3-RS [10] or THOR-50M [11] that is capable of measuring compression of the abdomen and chest, and for calculating the injury criteria listed in Section 5.1.2. The H3-RS ATD(s) shall meet the specifications in RSSB's specification report [10] and the requirements in NHTSA's 2005 certification manual [12]. The THOR-50M ATD(s) shall meet the requirements in NHTSA's September 2018 qualification manual [13]. Both the H3-RS and THOR-50M ATDs shall also demonstrate biofidelity in the lower abdomen and upper abdomen per NHTSA's biomechanical response requirements [14] up to the performance limit in this standard for internal abdomen compression.

The H3-RS or THOR-50M ATD shall be placed in the seat position nearest the wall. Standard Hybrid-III 50th percentile male (H3-50M) ATD(s) shall be used in the other seat position(s) if additional H3-RS or THOR-50M ATDs are not available. The H3-50M ATD(s) shall comply with 49 CFR 572, Subpart E. If there is concern that the H3-50M rotary chest potentiometer may malfunction or provide unreliable data, then at the discretion of the purchaser:

- Multiple Option A sled tests may be conducted: one test as described above, and an additional test(s) with the H3-RS or THOR-50M ATD in each of the other seat position(s) (i.e., aisle, center), using H3-50M ATD(s) in the remaining seat position(s); or
- H3-RS or THOR-50M ATD(s) may be used in all seat positions.

The adjustment, positioning and care of all ATDs used in the testing process shall comply with SAE standard AS8049 Rev. A, "Performance Standards for Single-Occupant, Side-Facing Seats in Civil Rotorcraft, Transport Aircraft, and General Aviation Aircraft.” The additional ATD instructions below shall supersede the guidance in AS8049 if they are in conflict.

Each ATD shall be clothed in a form-fitting cotton stretch garment with short sleeves and mid-thigh-length bottoms. The ATDs shall also be fitted with shoes per their respective user manual [11, 15]. Each ATD shall be centered in the seat, in as nearly symmetrical a position as possible and in a uniform manner to obtain consistent test results. The ATD components shall be positioned as follows:

- Back shall be placed against the seat back without clearance.
- The centerlines of the knees shall be separated by 6.7 ± 0.4 in. (170 ± 10 mm) for 50th-percentile male ATDs. The intent is for the ATDs’ thighs to be approximately parallel.
- Hands shall be placed on the thighs, palms down, as shown in **Figure 2**. Alternatively, the hands may be placed on top of the table.
- Feet shall be placed flat on the floor so that the centerlines of the lower legs are approximately parallel.
- Lower legs shall be placed as close to vertical as possible.
- Colored chalk shall be applied to surfaces on the ATDs that are likely to contact the table or the facing seats in order to aid in interpretation of results.

The ATDs may be tethered to the sled to prevent damage to the ATDs; however, tethering shall not restrict the motion of the ATDs such that evaluation of compartmentalization is impeded.

See **Figure 2** for a schematic of the sled configuration. The test sled shall be subjected to an 8g, 250 ms crash pulse, as shown in **Figure 3**. The measured crash pulse shall comply with the requirements established in SAE AS8049, Rev. A (refer to Section 5.3.9.2 and Appendix A of the standard) with the longitudinal crash pulse properties specified in **Table 1**.

FIGURE 2
Schematic of Sled Configuration

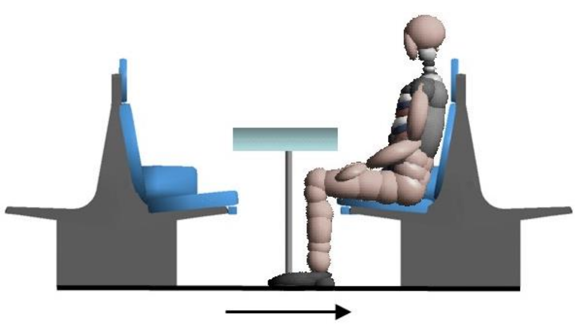


FIGURE 3
Longitudinal Crash Pulse

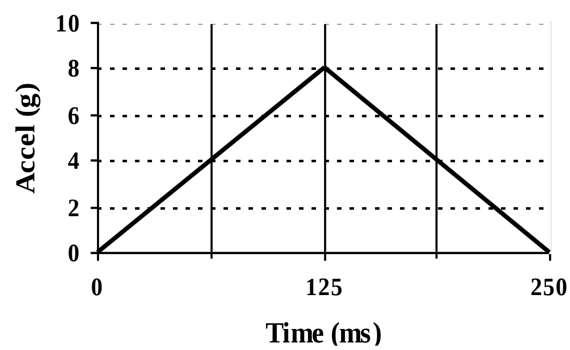


TABLE 1
Longitudinal Crash Pulse Properties

Properties	Requirements
G_{req}	8g
T_{req}	125 ms
V	21.94 mph (9.807 m/s)
V_{tr}	10.97 mph (4.903 m/s)

As an acceptable deviation, a peak sled deceleration (G_{req}) that is between 7.84g and 8g occurring prior to required rise time (T_{req}) is permissible if the change in velocity (V) is at least 23.03 mph (10.297 m/s) and the change in velocity at the rise time (V_{tr}) is at least 11.52 mph (5.148 m/s). The calculated human injury criteria must also be at least 5% below the allowable limits shown in **Table 4**. This deviation from the longitudinal crash pulse requirements is provided to allow for variables that may influence the crash pulse, such as seat stiffness.

For workstation tables that have deployable tabletop extensions, hinged leaves or the like, one dynamic test with the extensions in the stowed position (and one quasi-static test if Option B is used) is sufficient if the deployable elements can be placed in the stowed position with a longitudinal force less than 25 lbf (111 N), or if the extensions revert to the stowed position due to the inertia of the test sled prior to contact with the ATD. If greater force or inertia is required to stow the extensions, or if the extensions do not revert to the stowed position during the test, then the dynamic and quasi-static (if Option B is used) tests shall be conducted twice: once with all tabletop extensions in the stowed position and once with all tabletop extensions in the deployed position.

5.1.2 Dynamic sled test measurement and documentation requirements

The test shall be captured using high-speed video cameras providing an overhead view (plan view) and a side view (elevation view). Lighting shall be sufficient for high-quality analysis of the recording. Pre- and post-test still digital photographs of the test configuration shall be taken. At a minimum, photographs of the test sled should be taken from all four sides. Photos depicting pre- and post-test measurements (below) shall be taken, as well as close-up photographs of the seats and tables, to document any damage.

The test data (raw and filtered) in **Table 2** shall be obtained for each ATD during the test in accordance with SAE J211/1 except where noted.

TABLE 2
Test Data to be Collected Raw and Filtered

Test Data	ATD	CFC Filter
Triaxial head acceleration-time history	all	1000
Triaxial chest† acceleration-time history	all	180
Axial left and right femur force-time history	all	600
Upper neck extension/flexion bending moment time history	all	600
Upper neck axial force time history	all	600
Upper neck shear force time history	all	600
Bilateral upper and lower chest compression-time history	H3-RS or THOR-50M	180††
Bilateral upper and lower abdominal compression-time history	H3-RS	180
Bilateral abdominal compression-time history	THOR-50M	180
Chest (i.e., sternum) compression-time history	H3-50M	600
Longitudinal acceleration-time history of the test sled	all	60

† Triple axis accelerometer pack located near the mid-thoracic spine (T4-T6)
†† Deviation from SAE J211/1 to follow procedure from Craig et al. [7]

Targets visible from the overhead and side view cameras shall be placed on the tabletop for the purpose of evaluating the minimum available space between the tabletop and the rear-facing seats. The distance between the targets shall be measured and recorded in the test report for use in obtaining the measurement from the test video. Inch tape or centimeter tape shall be placed on the center of the unoccupied seat bottom cushions (front to back) to assist in evaluating the survival space. A target shall be securely fastened to each unoccupied seat back at the height of the tabletop to assist in evaluating survival space.

The following measurements in **Table 3** (see corresponding schematic in **Figure 4**) shall be taken at each seat position before (pre-test) and after (post-test) the test. These measurements are needed to evaluate the test results and as documentation for potential configuration modification allowances provided in Section 6. The measurements shall be photographed with a tape measure in place to document the measured distance to a resolution of 1⁄32 in. or 1 mm, and the photos shall be included in the test report.

TABLE 3
Test Measurements in Resolution of 1⁄32 in. or 1 mm

ID	Measurement
A	Longitudinal distance (in a horizontal plane) between tabletop and center of seat back at occupied seating position
B	Longitudinal distance (in a horizontal plane) between tabletop and center of seat back at unoccupied seating position
C	Longitudinal distance (in a horizontal plane) between seat back cushion of the launch seat(s) and the seat bottom cushion on the side opposite of the table from the ATD, at the height of the front of the seat bottom cushion
D	Vertical distance between top of tabletop and the simulated carbody floor measured at occupied seating position
D_1	If able, push tabletop down by hand (post-test only) and take measurement *D* again, at the highest point of the table.
E	Vertical distance between top of tabletop and the simulated carbody floor measured at unoccupied seating position
F	Vertical distance between top of tabletop and the highest point on the seat bottom cushion measured at the center of the occupied seating position

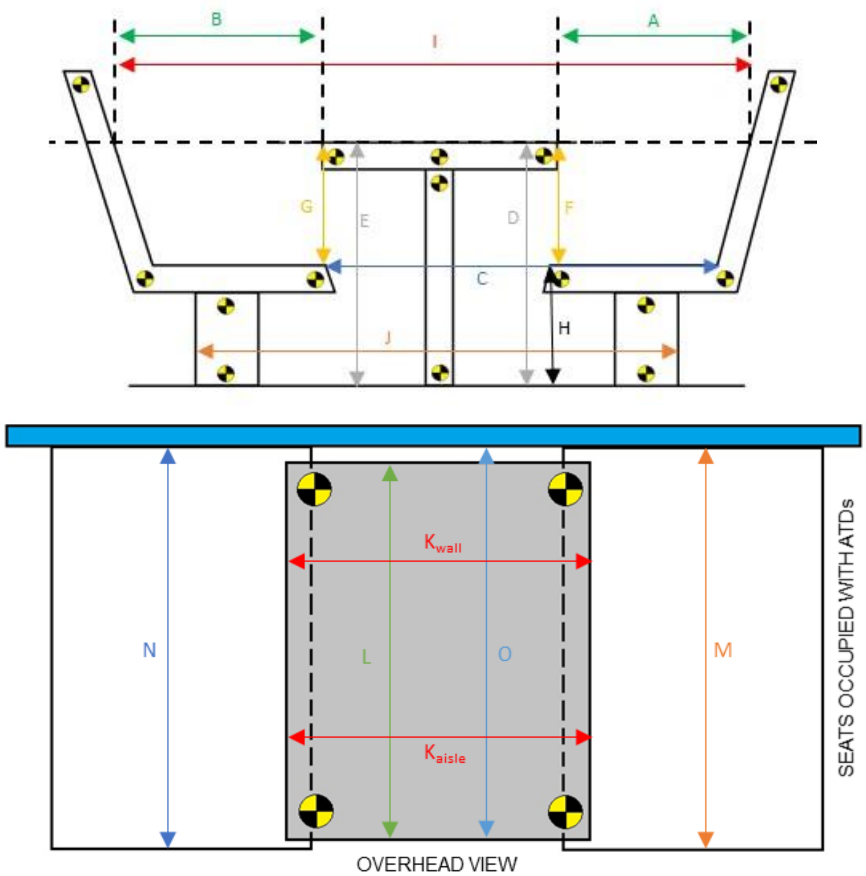
TABLE 3

Test Measurements in Resolution of 1⁄32 in. or 1 mm

ID	Measurement
G	Vertical distance between top of tabletop and the highest point on the seat bottom cushion measured at the center of the unoccupied seating position
H	Vertical distance between the simulated carbody floor and the top of the seat bottom cushion at the center of each occupied seating position
I	Longitudinal distance (in a horizontal plane) from seat back cushion of launch seat to seat back cushion of facing seat, measured at the height of the tabletop
J	Longitudinal distance (in a horizontal plane) from the outside edge of the occupied-seat pedestal to the outside edge of the unoccupied-seat pedestal
K	Overall width of table being tested measured at the center of each occupant's seating position
L	Overall length of table being tested
M	Lateral distance (in a horizontal plane) between outside edge of occupied seat and the wall of the simulated carbody
N	Lateral distance (in a horizontal plane) between outside edge of unoccupied seat and the wall of the simulated carbody
O	Lateral distance (in a horizontal plane) between outside edge of tabletop and the wall of the simulated carbody

FIGURE 4

Schematic Depicting Pre- and Post-Test Measurements



Before and after the test, inspect the chest potentiometer in the standard H3-50M ATD(s) (if used) to verify that the steel ball is securely positioned and slides freely in the guide track mounted behind the sternum of the ATD. The status of the ball position before and after the tests shall be noted in the test report.

The following injury criteria shall be computed for each ATD (per the definitions described at the end of this document):

- head injury criterion (HIC_{15}) over any 15 ms interval
- maximum resultant chest acceleration over any 3 ms interval
- peak axial tension and compression femur loads
- peak axial tension and compression upper neck loads
- neck injury criterion (N_{ij})
- peak bilateral upper and lower chest compressions (if H3-RS or THOR-50M used)
- peak bilateral upper and lower abdominal compressions (if H3-RS used)
- peak bilateral abdominal compressions (if THOR-50M used)
- peak chest (i.e., sternum) compression (if H3-50M ATD used)

The time-history data shall be reviewed to verify that all data channels functioned as intended. If there are obvious nonphysical data anomalies or discontinuities indicating sensor malfunction, then the erroneous data may be ignored if there is confidence that the allowable injury criteria were not exceeded due to physical forces. For example, data with a spike of 1 to 2 ms in duration that is three times higher than the allowable criterion, but otherwise less than the allowable criterion, is likely caused by a pinched cable or sensor malfunction, and not by a physical force.

Unless otherwise indicated, instrumentation for data acquisition, data channel frequency class and moment calculations are the same as those given for 49 CFR Part 572, Subpart E, “Hybrid-III Anthropomorphic Test Device.”

5.1.3 Dynamic sled test performance requirements

For a successful test, the following requirements must be met:

1. The table and any table components must remain attached to the simulated car structure, except for superficial, nonstructural components of negligible weight that do not affect the structural integrity of the table.
2. The table shall not penetrate the survival space reserved for occupants in the facing seat, so as not to injure or entrap the facing passengers or prevent egress. The survival space between the table and the seat back of the seat opposite the ATD, as depicted by measurement *B* in **Figure 4**, shall be greater than or equal to 9.7 in. (246.4 mm) - i.e., the maximum skeletal depth of the chest of the 95th percentile Hybrid-III male ATD [16] - at any point between the wall and the aisle, as measured from the test video throughout the duration of the test. A screenshot from the test video depicting the time at which the minimum survival space is measured, and the minimum longitudinal distance between the tabletop and the rear-facing seat, shall be included in the test report. If a table has extensions that were deployed prior to the test or during the test, survival space shall be evaluated with the extensions in the stowed position if the force to stow is less than 25 lbf (111 N). If the extension cannot be fully stowed with the application of a 25 lbf (111 N) force, then the survival space shall be evaluated with the extensions deployed.
3. The ATDs shall be compartmentalized, as defined in the Definitions section at the end of this document.

4. All injury measurements computed in Section 5.1.2 must meet the criteria in **Table 4** for each ATD. The injury criteria are defined in the Definitions section at the end of this document:

TABLE 4
Human Injury Criteria Performance Requirements for ATDs

Injury Criterion	H3-50M	H3-RS	THOR-50M
HIC_{15}	700	700	700
N_{ij}	1.0	1.0	1.0
F_z (tension)	+938 lbf (+4.17 kN)	+938 lbf (+4.17 kN)	+938 lbf (+4.17 kN)
F_z (compression)	−899 lbf (−4 kN)	−899 lbf (−4 kN)	−899 lbf (−4 kN)
Chest acceleration	60 g	60 g	60 g
Chest compression	2.5 in. (63 mm)†	2.76 in. (70 mm)	2.76 in. (70 mm)
Abdomen compression	N/A	2.64 in. (67 mm)	3.39 in. (86 mm)
Axial femur load	±2250 lbf (±10 kN)	±2250 lbf (±10 kN)	±2250 lbf (±10 kN)

† The chest compression injury criterion for the H3-50M can be excluded at the discretion of the purchaser if the rotary potentiometer is shown to be working prior to the test and is damaged or dislodged during the test. For reference, the rotary potentiometer has been observed to dislodge in tests where values of measurement *F* in **Figure 4** are less than approximately 11.6 in. (295 mm).

5.2 Option B: Dynamic sled test with standard H3-50M ATD coupled with quasi-static testing

To demonstrate table crashworthiness using Option B, the following two tests shall be conducted:

- a dynamic sled test with standard Hybrid-III 50th percentile male ATDs; and
- a quasi-static destructive loading test.

The purpose of the dynamic sled test is to demonstrate that:

- the table remains attached to the test sled;
- the table effectively compartmentalizes the occupants; and
- the table effectively limits human injury for the head, chest, neck and femurs.

The purpose of the quasi-static test is to demonstrate that the table effectively absorbs kinetic energy, while limiting the contact force between the occupants and the table. The performance requirements for this test were chosen to limit injury to the abdomen.

5.2.1 Dynamic sled test

The test conditions, measurement and documentation requirements, as well as performance requirements for the Option B dynamic sled test are described in this section.

5.2.1.1 Dynamic sled test conditions

The dynamic sled test for Option B shall be conducted according to the test conditions for Option A in Section 5.1.1, except that the ATDs shall all be standard Hybrid-III 50th percentile male (H3-50M) ATDs that comply with 49 CFR 572, Subpart E.

5.2.1.2 Dynamic sled test measurements and documentation requirements

The measurement and documentation requirements for Option B shall follow the instructions provided for Option A in Section 5.1.2, except for abdominal compression time history and injury criteria for abdominal compression.

5.2.1.3 Dynamic sled test performance requirements

The performance requirements for Option B shall follow the instructions provided for Option A in Section 5.1.3, except for injury criteria requirements for abdominal compression.

5.2.2 Quasi-static test

The test conditions, measurement and documentation requirements, as well as performance requirements for the Option B quasi-static test are described in this section.

5.2.2.1 Quasi-static test conditions

The quasi-static loading test is subject to the conditions in this section. A workstation table shall be mounted to a simulated car structure using the same fasteners or attachment mechanism used in service—bolts, screws, track, tapping plate, etc. The workstation table shall be destructively tested under quasi-static loading conditions.

The quasi-static test shall be conducted with the loads applied to the table independently but simultaneously via rigid body blocks (depicted in **Figure 5**), one per seating position, attached to hydraulic cylinders (see **Figure 6** for a schematic of the test setup). The body blocks shall be aligned laterally at the center of each seat position for the intended service. The body blocks shall be centered vertically on the table edge.

FIGURE 5
Body Block

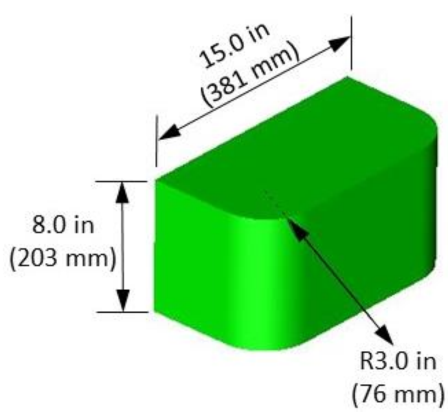
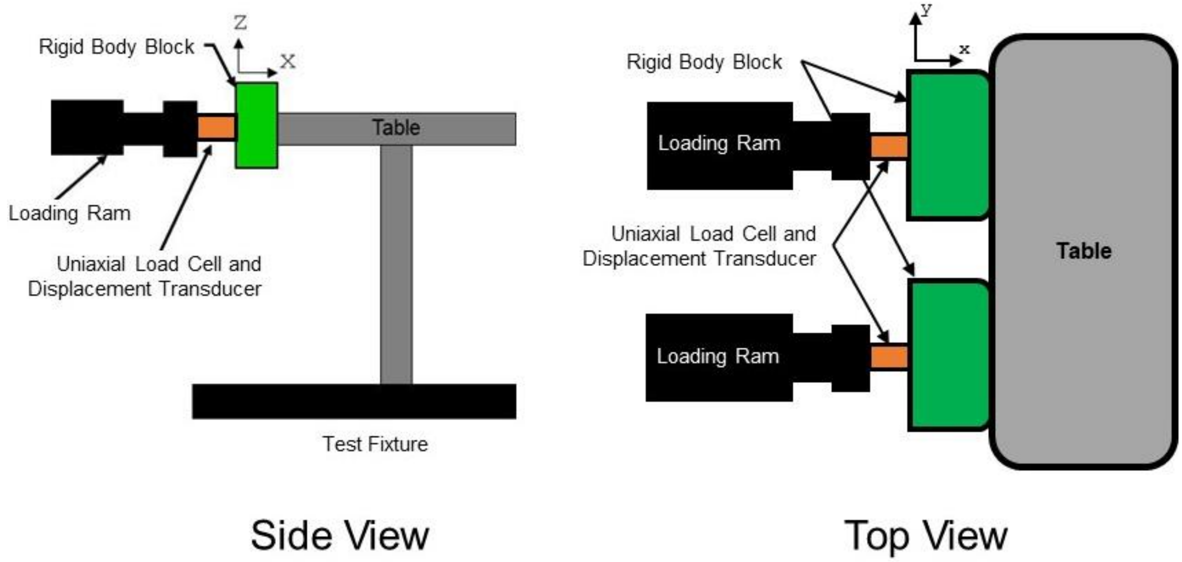


FIGURE 6
Schematic of Quasi-Static Test Setup



The rigid body blocks shall be loaded at the same time, with the goal of maintaining approximately the same force applied to the table edge at each body block position. If load control is used, then the load rate shall be approximately 250 to 500 lbf (1.1 to 2.2 kN) per minute. If displacement control is used, then the displacement rate shall be approximately 2 to 4 in. (50 to 100 mm) per minute. The loading of each hydraulic cylinder shall be stopped independently when the applied load at a single seat position reaches the allowable load limit or when maximum deflection of the loaded table edge has been achieved, whichever occurs first.

Load and displacement data shall be recorded until all body blocks are completely unloaded by reversing the motion of the loading rams. None of the body blocks shall be withdrawn until the applied load at each body block has reached the allowable load limit or the maximum deflection at each seat position has been achieved.

For workstation tables with deployable tabletop extensions, hinged leaves or the like, which can be placed in the stowed position with a longitudinal force less than 25 lbf (111 N), or if the extensions revert to the stowed position due to inertia of the test sled prior to contact with the ATD, one quasi-static test per Option B is sufficient. The tabletop extensions shall be placed in the stowed position for this test. If greater force or inertia is required to stow the extensions, then the quasi-static test shall be conducted twice: once with extensions in the stowed position and once with extensions in the deployed position.

5.2.2.2 Quasi-static test measurements and documentation requirements

The force-time history and displacement-time history of each loading ram shall be measured.

The energy absorbed by table deformation at each loading ram position shall be calculated as follows:

- Plot the table deflection time-history for each loading ram, where deflection is equal to the displacement of the loading ram, from t_0 to t_f:
  - t_0 = time that ram contacts the table
  - t_f = time that force returns to zero after unloading
- Cross-plot force versus deflection for each loading ram, from t_0 to t_f.

- For each ram, integrate the ram load versus ram displacement from the point where the ram contacts the table until the force reaches the allowable load limit or the maximum table deformation has been achieved to calculate the total energy absorbed (work) by the table at each seat position.
- The allowable load limit is 2250 lbf (10 kN) if: (1) vertical distance between top of tabletop and the highest point on the unoccupied seat bottom cushion (depicted as measurement *F* in **Figure 4**) is greater than 11.6 in. (295 mm); *and* (2) the chest (sternal) rotary potentiometer in each H3-50M ATD does not malfunction (e.g., dislodge) during the dynamic sled test in Section 5.2.1.
- Otherwise, the allowable load limit is 1800 lbf (8 kN) if: (1) the vertical distance between top of tabletop and the highest point on the unoccupied seat bottom cushion (depicted as measurement *F* in **Figure 4**) is less than 11.6 in. (295 mm); *or* (2) the chest (sternal) rotary potentiometer in either H3-50M ATD is shown to function properly before the test but malfunctions (e.g., dislodges) during the dynamic sled test in Section 5.2.1. (See Appendix A for a discussion on the reduction in load limit.)

Note that the allowable load limits specified are *not* to be construed as design guidelines. In general, lower deformation loads are associated with lower chest and abdomen deflections and lower risk of injury.

Still photographs of the table shall be taken pre- and post-test. The test shall also be recorded using a digital video camera at two locations (top and side views).

5.2.2.3 Quasi-static test performance requirements

For a successful test, the following requirements must be met:

1. The table and any table components must remain attached to the simulated railcar structure, except for superficial nonstructural components of negligible weight that do not affect the structural integrity of the table.
2. For each seat position, if the seat back distance, i.e., measurement *I* in **Figure 4**, is less than or equal to 57 in. (1448 mm), then the energy absorbed, as calculated above, must be at least 6250 in.-lbf (706.2 J).
3. For each seat position, if the seat back distance, i.e., measurement *I* in **Figure 4**, is greater than 57 in. (1448 mm), then the required energy absorption at each seat position is a linear function of measurement *I* according to Equation (1) when *I* is in inches and Equation (2) when *I* is in millimeters. (See Appendix A for a discussion on the bilinear energy absorption requirement.)

$$Energy \geq \left(530 \frac{\text{in.−lbf}}{\text{in.}} \right) \cdot I - (\,23{,}960\ \text{in.} - \text{lbf}\,) \tag{1}$$

$$Energy \geq \left(2.35756 \frac{\text{J}}{\text{mm}} \right) \cdot I - (2707.12\ \text{J}\,) \tag{2}$$

6. Test implementation plan, procedures and report

All testing performed by the table manufacturer (or its designee) shall be documented with a test implementation plan, test procedures and test report. The test implementation plan and test procedures shall be submitted and approved by the purchaser prior to testing. Tests should be scheduled to allow the purchaser and invited participants to witness the testing. The purchaser may elect to accept existing test reports and procedures, provided that the table to be purchased is demonstrated to be structurally identical to that tested and that the test reports and procedures meet the requirements listed in this section.

If a structurally identical table design of a specific configuration and simulated car structure has been previously tested and has met all applicable requirements of this standard, then the table does not have to be retested for relative seat/table geometry variations, provided that the parameter modifications are within the defined acceptable tolerance ranges below:

1. Longitudinal distance (in a horizontal plane) between the front edge of the tabletop and the seat back (depicted as dimension *A* in **Figure 4**): +0/−3 in. (+0/−76.2 mm). If dimension *A* for the design of the untested table arrangement is less than the dimension in the design of the original tested configuration, then the difference must be subtracted from the survival space (measurement *B*) to ensure that the untested table arrangement would still comply with the 9.7 in. (246.4 mm) minimum requirement.
2. Vertical distance between top of the tabletop and the highest point on the seat bottom cushion (depicted as dimension *F* in **Figure 4**): +1 in./ −0 in. (+25.4 mm/−0 mm).

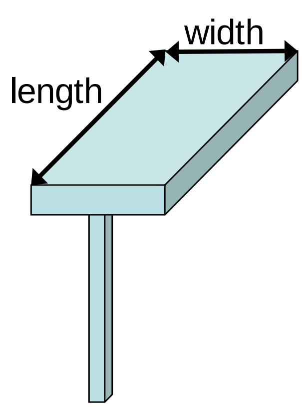
Additionally, the car manufacturer shall demonstrate that the carbody structure in the new installation provides an attachment strength equal to or greater than that of the configuration previously tested.

The dynamic sled test described in this standard is intended to simulate the ATD-to-floor interface, which shall include the finished floor material (carpet, rubber flooring, composite resin, etc.) intended for use in service. Should a qualified table system be used on another program or undergo a refurbishment at a later date with a different floor covering chosen, a repeat test is not required solely on the basis of a different floor covering.

It may be desirable to manufacture a table with slightly different tabletop geometry for different applications. If minor geometrical changes are made to an otherwise structurally identical table design that has been tested and has met all the requirements of this standard, including the allowable parameter variations described in the previous paragraphs, then it does not need to be retested if the geometric changes are within the defined acceptable tolerance range below:

Tabletop length (see **Figure 7**): ±2 in. (±50.8 mm), provided that the table still complies with the geometry requirements in Section 3.

FIGURE 7
Schematic of Tabletop Geometry Definitions



6.1 Test implementation plan

The test implementation plan shall describe how the tests will be conducted, including a description of the test fixtures, instrumentation and data acquisition system. Prior to table testing, a test plan shall be submitted by the table manufacturer to the purchaser. The final test plan shall be reviewed and approved by the purchaser.

6.2 Test procedures

A set of procedures for each test shall be prepared by the table manufacturer and submitted for approval to the purchaser. The test procedures shall at a minimum include the following:

- test objective
- complete description of test article
- pass/fail criteria
- list of test equipment
- drawings of test setup
- description of the attachment of the table to the text fixture/load cells
- location of tests
- sequential, step-by-step test procedure
- test data sheets (for recording data during testing)
- drawing of the assembled seats depicting all dimensions of the assembly, with references to the floor and adjacent facing seats and table

6.3 Test reports

Test reports shall at a minimum include the following:

- test requirements
- text or cover letter that provides a summary of the test results, the date and location of the test, and the signature of the person or people responsible for conducting the test and writing the report
- calibration certificates for all test measuring equipment
- pre- and post-test measurements (dimensions, etc.)
- calculated injury criteria, per test requirements
- graphical output of all data channels
- test videos
- pre- and post-test photos

7. Flammability, smoke emission and toxicity

Materials used in table construction shall meet the requirements given in 49 CFR Part 238, Appendix B.

8. Engineering drawings

As part of its work and prior to the supply of tables, the table manufacturer shall submit engineering drawings for approval. The drawings shall, at a minimum, include the following:

- overall dimensions and tolerances of the table assembly
- weight and location of the center of gravity of the table assembly
- mounting requirements, including hole sizes, recommended bolt sizes and torque requirements, and recommended grade of bolts to be used for mounting
- list of materials of construction

9. Submittals for approval

Prior to acceptance of the table by the purchaser, the table manufacturer shall submit the documentation listed in **Table 5** for approval by the purchaser.

TABLE 5
Submittals

Submittal	Reference Standard Section
Operational quasi-static test report	4
Crashworthiness testing report	5
Test implementation plan	6.1
Test procedures	6.2
Test reports	6.3
Flammability and smoke emission report(s)	7
Engineering drawings	8

As an option, submittals from previous table procurements may be submitted to satisfy this requirement as negotiated by the purchaser and table manufacturer, provided that any deviations from previously tested tables are within the acceptable tolerance range defined in Section 6.

10. Procurement specifications

This standard is intended to be supplemented by procurement specifications prepared by the purchaser and directed to the table manufacturer.

Related APTA standards

APTA PR-CS-S-006-98 Rev. 1, "Attachment Strength of Interior Fittings for Passenger Railroad Equipment"
APTA PR-CS-S-016-99 Rev. 3, "Passenger Seats in Passenger Rail Cars"

References

This standard shall be used in conjunction with the following regulations, standards and recommended practices. When the following documents are superseded by an approved revision, the revision shall apply:

Code of Federal Regulations:
- 49 CFR Part 238, Section 233: Interior Fittings and Surfaces
- 49 CFR Part 571, Section 208: Federal Motor Vehicle Safety Standards
- 49 CFR Part 572, Anthropomorphic Test Devices

SAE International:
- J211/1, "Instrumentation for Impact Test - Part 1 - Electronic Instrumentation," March 2014
- AS8049, Rev. D, "Performance Standard for Seats in Civil Rotorcraft, Transport Aircraft, and General Aviation Aircraft"
- J1727, "Calculation Guidelines for Impact Testing," February 2015

Rail Safety and Standards Board, GM/RT2100, Issue 6, "Requirements for Rail Vehicle Structures," Railway Group Standard, United Kingdom, Rail Safety and Standards Board Ltd., March 2020.

Union des Industries Ferroviaires Européennes, UNIFE REF 001, Issue 1, "Technical Report for Interior Passive Safety in Railway Vehicles," European Rail Industry Association, December 2014.

Definitions

abdominal compression criterion: Absolute maximum x-axis abdominal deflection for all abdominal deflection sensors, filtered at CFC180.

$$\delta_{max} = |\delta(t)|_{max}$$

- $\delta(t)$ = instantaneous x-axis abdominal deflection (mm) for each deflection sensor in the abdomen test device
- δ_{max} = absolute maximum x-axis abdominal compression
- δ_{max} shall not exceed 2.64 in. (67 mm) for the H3-RS and 3.39 in. (86 mm) for the THOR-50M

NOTE: Refer to Appendix B: Human injury criteria for a discussion on the specification of the abdomen compression performance requirements.

adjustable tables: Fixed tables that have moveable parts, such as a hinged or sliding portion of the tabletop, designed for improved ingress/egress.

axial femur load criterion: Peak axial femur load (F_z), filtered at CFC600. F_z has a limit of 2248 lbf (10 kN) in tension and compression. This performance requirement is from 49 CFR 571.208.

chest compression criterion: Peak x-axis deflection measured at each chest deflection sensor, filtered at CFC600 for H3-50M and at CFC180 for THOR-50M and H3-RS.

$$D_{max} = |D(t)|_{max}$$

- $D(t)$ = instantaneous x-axis chest deflection (mm) for each deflection sensor in the chest test device
- D_{max} = absolute maximum chest compression criterion; shall not exceed 63 mm for any H3-50M* and 70 mm for any H3-RS or THOR-50M ATDs

  * At the discretion of the purchaser, this requirement may be excluded for the H3-50M ATD when the rotary potentiometer is shown to be functioning prior to the test but fails—e.g., the ball at the end of the radial arm is dislodged from the guide track behind the sternum—during the test.

chest acceleration criterion: The resultant mid-thoracic spine (T4–T6) deceleration, filtered at CFC180, shall not exceed 60g, except for intervals whose cumulative duration is not more than 3 ms. This performance requirement is from 49 CFR 571.208.

coach seating: Revenue seats in passenger cars (including cab cars), in all classes of service—business, first class, coach, economy, etc.

compartmentalization: An interior design strategy that aims to contain occupants between rows of seats or between seats and tables during a collision, preventing occupants from traveling over seats or tables and impacting other passengers and hostile objects. During sled testing, ATD compartmentalization is evaluated until the point of maximum forward progress of the ATD. The ATD must be confined between the workstation table (potentially deformed) and the initially occupied seat until the ATD begins to rebound and move away from the impacted table.

deployable tabletop extensions: Fixed tables that have moveable parts, such as a hinged or sliding portion of the tabletop, designed for improved ingress/egress.

facing seats: Adjacent rows of passenger rail coach seats where one row of seats is facing forward and one row of seats is facing backward. These seating configurations are referred to as face-to-face seats, or open-bay seats when a workstation table is not present.

femur axial compression/tension criterion: Peak compressive and tensile axial (F_z) loads measured at the femur load cell, filtered at CFC600. The performance requirement of 2250 lbf (10 kN) in compression and tension is from 49 CFR 571.208.

fixed tables: Tables that are permanently affixed to the railcar. Tray tables attached to seat backs are not considered fixed tables and are not subject to the requirements of this standard.

HIC15 (head injury criterion): A value calculated according to the following formula, using the resultant head acceleration, filtered at CFC1000. The performance requirement of 700 is from 49 CFR 571.208.

$$HIC_{15} = \left| (t_2 - t_1) \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} \right|_{max}$$

- t_1, t_2 = any two points in time during the head impact, in seconds
- $a(t)$ = the resultant head acceleration during head impact (g)
- The subscript indicates that the time interval between t_1 and t_2 is limited to 0.015 s
- HIC_{15} shall not exceed 700 for any ATD

ingress/egress space: Space available for passengers to occupy or leave an occupant space. This has importance for both normal passenger seating and also for emergency exit considerations.

lateral: The direction in a horizontal plane perpendicular to the direction of travel.

longitudinal: The direction in a horizontal plane parallel to the direction of travel.

neck axial compression criterion: Peak compressive axial (F_z) load measured at the upper neck load cell, filtered at CFC1000. The performance requirement of 4 kN (899 lbf) is from 49 CFR 571.208.

neck axial tension criterion: Peak tensile axial (F_z) load measured at the upper neck load cell, filtered at CFC1000. The performance requirement of 4.17 kN (937 lbf) is from 49 CFR 571.208.

N_{ij} (neck injury criterion): A set of four values (tension-extension [N_{te}], tension-flexion [N_{tf}], compression-extension [N_{ce}], and compression-flexion [N_{cf}]) calculated according to the loading condition. At each point in time, only one of the four loading conditions occurs and the N_{ij} value corresponding to that loading condition is computed, and the three remaining loading modes shall be considered to have a value of zero. The formula for calculating each N_{ij} loading condition is given by the following formula. The performance requirement of 1.0 for each of the loading conditions is from 49 CFR 571.208.

$$N_{ij} = \left| \frac{F_z(t)}{F_{zc}} + \frac{M_y(t)}{M_{yc}} \right|_{max}$$

- $F_z(t)$ = axial tension/compression upper neck load-time history filtered at CFC600
- F_{zc} = critical values used for normalization; refer to **Table 6** for values from 49 CFR 571.208 for the H3-50M and H3-RS and from Craig et al. [7] for the THOR-50M
- $M_y(t)$ = flexion/extension neck bending moment-time history at the occipital condyle filtered at CFC600
- M_{yc} = critical value used for normalization; refer to **Table 6** for values from 49 CFR 571.208 for the H3-50M and H3-RS and from Craig et al. [7] for the THOR-50M
- F_x = shear upper neck load-time history, used to compute the neck bending moment, M_{ocy}, about the occipital condyle in the H3-50M and H3-RS per SAE J1727, filtered at CFC600
- N_{ij} shall not exceed 1.0 for each of the four loading conditions in any ATD

TABLE 6
Neck Injury Criterion Critical Values

Parameter	State	H3-50M and H3-RS	THOR-50M
F_{zc}	Tension	1530 lbf (6806 N)	944 lbf (4200 N)
F_{zc}	Compression	−1385 lbf (−6160 N)	−1016 lbf (−4520 N)
M_{yc}	Flexion	229 lbf-ft (310 Nm)	44.3 lbf-ft (60 Nm)
M_{yc}	Extension	−100 lbf-ft (−135 Nm)	−58.4 lbf-ft (−79.2 Nm)

primary impact: The impact between the railcar and an object, such as another railcar, during a collision.

secondary impact: The impact of passengers with interior structures during a collision.

shall: Practices directed by “shall” are required.

tertiary impact: Another impact with the interior subsequent to a secondary impact during a collision. For example, a passenger may experience a secondary impact with a seat back and then a tertiary impact with another object in the car.

workstation table: A fixed interior table installed in a passenger rail coach car and positioned at revenue seats, consisting of a flat tabletop and its supporting structure that is often installed between facing seats.

Abbreviations and acronyms

AIS	Abbreviated Injury Scale
AAM	Alliance of Automotive Manufacturers
AIAM	Association of International Automobile Manufacturers
ATD	anthropomorphic test device
CEM	crash energy management
CFC	channel frequency class
CFR	Code of Federal Regulations
CTI	Combined Thoracic Index
FE	finite element
FMVSS	Federal Motor Vehicle Safety Standards
FRA	Federal Railroad Administration
g	acceleration due to gravity (9.80665 m/s^2)
H3-50M	Hybrid-III 50th percentile male
H3-RS	Hybrid-III Rail Safety
HIC	head injury criterion
IARV	injury assessment reference value
IR-TRACC	Infrared Telescoping Rod for Assessment of Chest Compression
kN	kilonewton
in.-lbf	inch-pound
MADYMO	MAthematical DYnamic MOdels
NCAP	New Car Assessment Program
NHTSA	National Highway Traffic Safety Administration
N_{ij}	neck injury criterion
NPRM	notice of proposed rulemaking
PMHS	post-mortem human surrogates
RSSB	Rail Safety and Standards Board

SAE SAE International, formerly the Society of Automotive Engineers
THOR Test device for Human Occupant Restraint
UNIFE Union des Industries Ferroviaires Européennes (Association of the European Rail Industry)
VC viscous criterion

Summary of document changes

The original version of this standard specified the use of an advanced test dummy capable of evaluating abdominal injury to demonstrate the crashworthiness of workstation tables in Section 5. Due to the limited availability of these test dummies, Rev. 1 offered an alternative set of crashworthiness requirements (Option B) with the intention that an equivalent level of safety would be provided by tables that comply with either crashworthiness option.

The first option is to conduct a dynamic 8g sled test using at least one advanced test dummy, as per the original version of this standard (Option A). The second option is to conduct a dynamic 8g sled test using standard Hybrid-III 50th percentile male test dummies, combined with a separate quasi-static destructive loading test. The quasi-static test (Option B) is needed to assess the risk of abdominal injury, in lieu of testing with a test dummy that is instrumented to evaluate abdominal injury.

It is presumed that once advanced test dummies become commercially available for testing in the United States, Option B will be removed so that all tables are tested per Option A.

Rev. 2 of this standard incorporates several edits intended for improved clarification or grammar. Several edits are the result of lessons learned after several years of table testing. Below is a summary of the more significant changes:

- The use of a seat opposite the table is required, rather than optional. The opposite seat is needed to absorb energy from the knee impact to keep the chest and abdomen deflections below the respective injury requirements. The seat is also useful to accurately evaluate the minimum space requirement.
- A simulated car structure is required, as per APTA PR-CS-S-016-99, Rev. 2, to ensure adequate wall/floor strength to react to the dynamic loads from the ATDs. Seat attachment directly to a rigid test fixture will no longer be permitted.
- Reference to Section 5.3.9.2 in SAE AS8049 was included to specify that for a test pulse to be acceptable, the change in velocity of the test crash pulse at the required rise time and end of the pulse must be equal to or greater than that of the idealized crash pulse. This requirement was always assumed and is explicitly defined in SAE AS8049.
- For clarification, added “bilateral upper and lower” for chest and abdomen injury. Also added text to indicate which measurements are associated with which ATDs. These changes were agreed to in Rev. 1, but the edits were erroneously omitted from the final version of Rev. 1.
- Additional pre- and post-test measurements are specified to assist in evaluation of permitted configuration modifications without needing to retest.
- Clarified how the post-test survival space is to be measured.
- The minimum survival space requirement was reduced to 9.7 in. (246.4 mm), which is the maximum chest depth of the 95th percentile ATD. This requirement is similar to the survival space requirement in UNIFE REF 001 and GM/RT 2100, Issue 6. The survival space shall be evaluated throughout the duration of the test using test video, not just measured post-test as in the prior revision. Initial space is often as small as 17 in. (432 mm). Any forward displacement/rotation of the seat back due to the mass of an occupant in the rear-facing seat would increase the survival space.
- The minimum survival space requirement has been removed from the quasi-static test requirements. It is already included in the dynamic sled test requirements, which is a more realistic collision condition.

- The chest deflection limit of the H3-RS and THOR-50M ATDs has been increased to achieve a similar level of safety with the H3-50M ATD (note that the original requirement was based on injury criteria for H3-50M ATD(s) in an automotive vehicle).
- The abdomen deflection limit of the THOR-50M ATD has been increased to account for the changes in instrumentation in the test device and to harmonize with the injury risk function specified by NHTSA; the abdomen deflection limit of the H3-RS ATD is unchanged.
- An exception has been added to account for observed failures in the H3-50M chest compression sensor (rotary potentiometer); however, the quasi-static performance requirements have been increased to not decrease the level of safety.
- The N_{ij} intercept values for the THOR-50M ATD have been updated to harmonize with NHTSA.
- The sources and derivations of various injury criteria have been clarified.

Document history

Document Version	Working Group Vote	Public Comment/ Technical Oversight	Rail CEO Approval	Policy & Planning Approval	Publish Date
First published	November 2012	January 2013	February 2013	March 2013	March 26, 2013
First revision	February 2015	—	—	—	Oct. 30, 2015
Second revision	June 14, 2022	August 12, 2022	October 10, 2022	October 25, 2022	Oct. 26, 2022

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Appendix A: History of the workstation table standard

Passenger rail accidents have resulted in serious chest and abdomen injuries due to occupant impacts with fixed workstation tables [1, 2, 3]. Tables that are thin and rigid can cause high contact forces during impacts with occupants that lead to sometimes-fatal injuries. Tables that effectively absorb the kinetic energy of moving occupants can reduce the risk of human injury to the head, neck, chest, abdomen and femurs by minimizing contact forces.

In the early 2000s, the U.S. Department of Transportation, Federal Railroad Administration (FRA), sponsored a research project with the John A. Volpe National Transportation Systems Center (Volpe) to develop a crashworthy fixed workstation table designed to: (1) reduce the risk of occupant injuries from impacts with tables and (2) compartmentalize occupants. A prototype cantilever table with a crushable aluminum honeycomb crash energy management (CEM) system was designed using the results of MADYMO® [17] modeling [18], manufactured and then tested quasi-statically and dynamically with rigid body blocks [19, 20] and tested with a THOR-NT and a prototype H3-RS in a full-scale CEM train-to-train test [21].

A literature review was conducted on standardized human injury criteria, and MADYMO modeling was conducted with a model of the FRA prototype table to determine suitable injury criteria for an impact between an adult male occupant and a crashworthy fixed workstation table [8]. A detailed description of the initial development of APTA PR-CS-S-018-13 was presented at the Passive Safety Symposium in Berlin in 2013 [22].

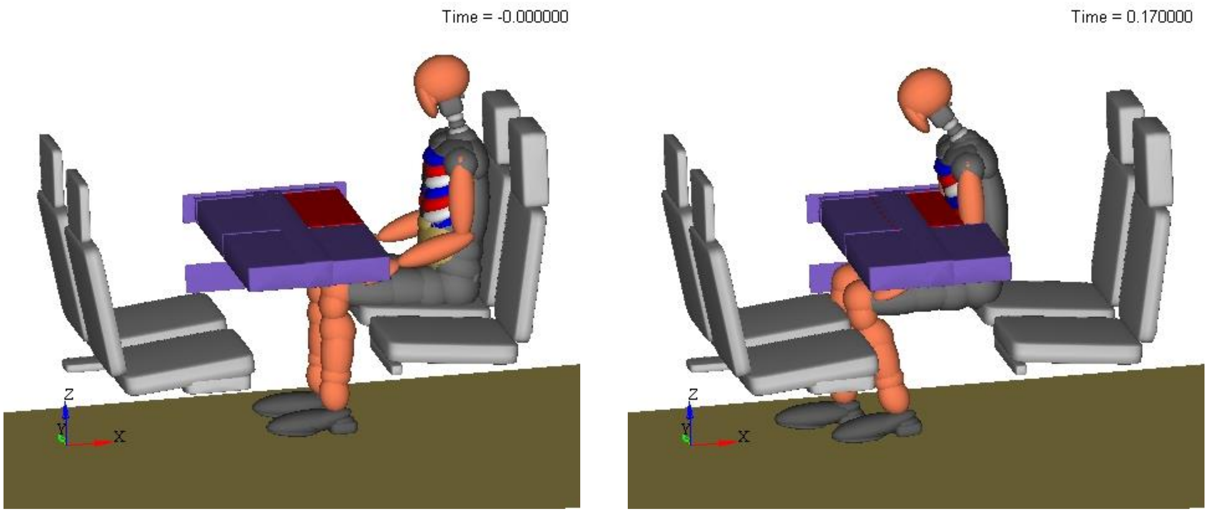
The original version of APTA PR-CS-S-018-13 was published March 26, 2013, shortly after GM/RT 2100, Issue 4 (December 2010), and used many of the same human injury criteria. APTA PR-CS-S-018-13 requires the use of an advanced frontal impact ATD, i.e., either a THOR or H3-RS, while GM/RT 2100 does not require an advanced ATD. GM/RT 2100, Issue 4 specified an abdominal VC criterion limit (1.98 m/s) but did not specify an abdomen compression performance limit for the H3-RS or THOR. Instead, GM/RT 2100, Issue 4, specified a limit for an ATD with a frangible abdomen insert, i.e., a modified H3-50M. It should be noted that as of June 2022, GM/RT 2100, Issue 6 adds an abdomen compression performance limit to match the performance limit in APTA PR-CS-S-018-13 (67 mm) and disallows the use of a frangible abdomen.

Rev. 1 of APTA PR-CS-S-018-13

Because the THOR and H3-RS were not widely available for table sled testing, APTA PR-CS-S-018-13 was revised (APTA PR-CS-S-018-13, Rev. 1) on October 30, 2015, adding Option B, which allowed the use of the H3-50M ATD in all forward-facing seat positions in the dynamic test. To account for the limitations in evaluating chest and abdominal injury criteria, Option B additionally required a destructive quasi-static test of the workstation table with performance requirements on energy absorption and allowable peak force. The performance requirements in Option B were specified with the intention of achieving safety equivalence with the injury criteria in Option A.

The quasi-static test in Rev. 1 set a minimum energy absorption capacity of 6250 in.-lbf (706.2 J) at each seat position when subjected to independent, simultaneous loads up to a maximum of 2250 lbf (10 kN) at each seat position. The quasi-static requirements were specified based on previously described experimentation with the FRA prototype table and parametric analyses in MADYMO (see **Figure 8**) [8].

FIGURE 8
MADYMO Model of Sled Test with FRA Prototype Table and THOR ATD



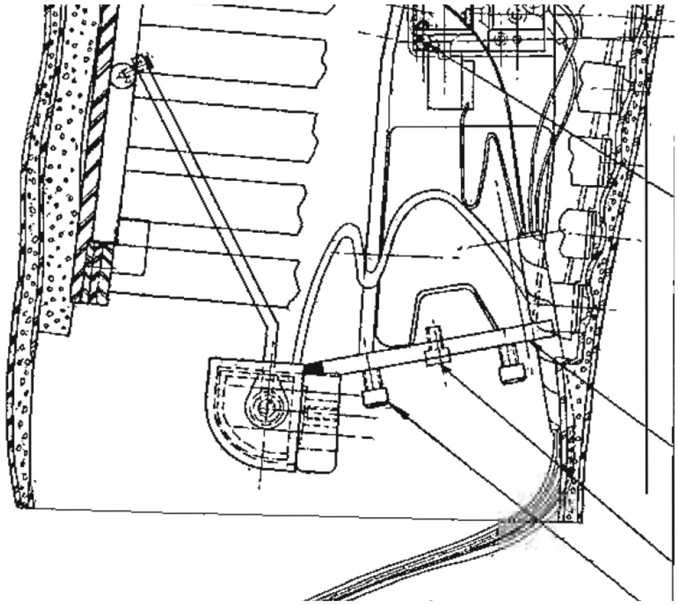
Rev. 2 of APTA PR-CS-S-018-13

After APTA PR-CS-S-018-13 was published, the FRA Office of Research, Development, and Technology sponsored additional testing with technical advisement from Volpe:

1. In 2014, the Transport Research Laboratory (TRL) dynamically tested and finalized the design of the abdomen test device in the H3-RS [23].
2. In 2015, TRL dynamically tested six anonymously donated tables with the H3-RS per Option A of APTA PR-CS-S-018-13, Rev. 1 [24, 25].
3. In 2016, Sharma & Associates quasi-statically tested two of the table designs per Option B of APTA PR-CS-S-018-13, Rev. 1 [25, 26].
4. In 2020, Calspan dynamically tested the abdomen test device in the THOR-50M [27].
5. In 2021, MGA dynamically tested five anonymously donated table designs with the THOR-50M per Option A of APTA PR-CS-S-018-13, Rev. 2 (Sept. 15, 2020, draft) [28].
6. In 2021, MGA dynamically and quasi-statically tested three anonymously donated tables per Option B of APTA PR-CS-S-018-13, Rev. 2 (Sept. 15, 2020, draft) [28, 29].

After the publication of APTA PR-CS-S-018-13, Rev. 1, review of dynamic and quasi-static table test results indicated that additional considerations should be made in Rev. 2 for factors that influence human injury criteria, such as the allowable peak contact force, table height, seat pitch and instrumentation failure. It was observed that low tables tended to cause instrumentation failure in the chest deflection sensor of the H3-50M ATD (see **Figure 9**), resulting in inconclusive data for critical human injury measurements. Because the H3-50M ATD was not designed for table impacts, it was recommended that exceptions should be made when the H3-50M chest deflection sensor fails (dislodges from its base) during a test, but in doing so the quasi-static work requirements (peak force and energy absorption) should also be reevaluated to ensure that the intended level of safety for occupants is maintained.

FIGURE 9
General Motors Drawing 78051-89 of H3-50M Upper Torso Assembly Showing Rotary Chest Potentiometer



(Drawing incorporated by reference in CFR 49, Part 572, Subpart E)

It was observed that some tables that met the Rev. 1 Option B quasi-static performance requirements did not meet the associated dynamic sled performance requirements [24, 26]. It was concluded that the performance requirements in the quasi-static test and dynamic test were not equivalent from a safety perspective because seat/table configurations with a large seat pitch (see **Figure 1**) or without an impact (rear-facing or opposing) seat required a table design with a higher energy absorption capacity due to the rear-facing seat not impeding the motion of the ATD [30].

Description of finite element model

Because of the lack of equivalence between the dynamic and quasi-static performance requirements in Option B of Rev. 1 of APTA PR-CS-S-018-13 for some configurations, the quasi-static performance requirements were re-specified to achieve improved safety equivalence with Option A based on the results of testing and finite element (FE) analysis in LS-DYNA® [31] (see **Figure 9**) of the Option A sled test [30, 32, 33].

FIGURE 10
Diagram of LS-DYNA Model with Annotations of Seat and Table Configuration Parameters

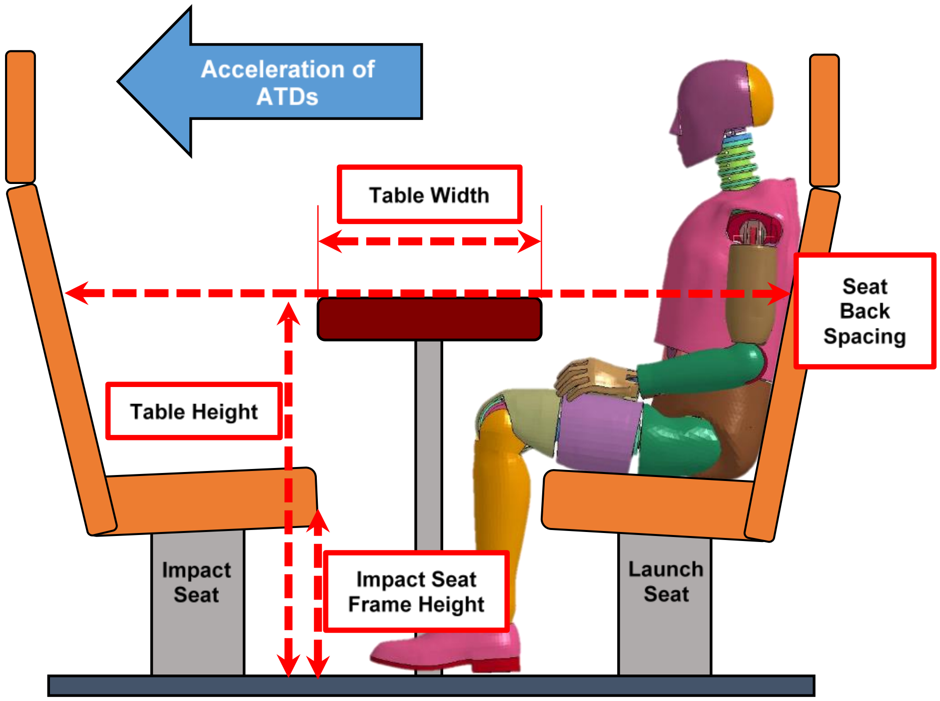


Table 7 shows the range of values considered for parameters in seating and table configurations in the FE model. Simulation results revealed that the table's energy absorption under dynamic loading from ATDs was strongly dependent on seat back spacing. Larger seat back spacing resulted in higher impact speeds between the ATD and the table and less energy absorption contribution from the impact seat frame.

TABLE 7
Range of Seat and Table Configurations Simulated in LS-DYNA

FEM Properties	Value	
	U.S. Customary	SI
Table height	28.5–30.5 in.	725–775 mm
Table length	42 in.	1075 mm
Table width	20.2–32.1 in.	515–815 mm
Table thickness	2.5 in.	63.5 mm
Seat back spacing†	55–67 in.	1400–1700 mm
Seat frame height††	13.4–15.4 in.	340–390 mm

† Seat back spacing is measured from the facing seat back cushions at the height of the tabletop.
†† Seat frame height is measured from the floor to the top of the structural part of the seat bottom frame.

In addition to seat back spacing, another seating configuration parameter that has a correlation with table energy absorption is the impact seat frame height (see **Figure 10**). **Figure 11** shows differing amounts of ATD knee override of the impact seat with a high seat frame [21] (left) and a low seat frame [24] (right) with crashworthy cantilever table designs. Higher seat bottom frames tend to have higher contact forces with the

ATDs, doing more to arrest the motion of the ATDs. While the contact forces did increase, none of the configurations resulted in axial femur loads that exceeded the performance limit of 2248 lbf (10 kN). It should be noted that tibial loads may be a more appropriate indicator of leg injury for impacts with passenger rail seats; however, requirements for tibial loads have not yet been added to this standard because they have not been observed to cause fatalities in U.S. passenger rail accidents.

FIGURE 11
Comparison of ATD Override of the Impact Seat

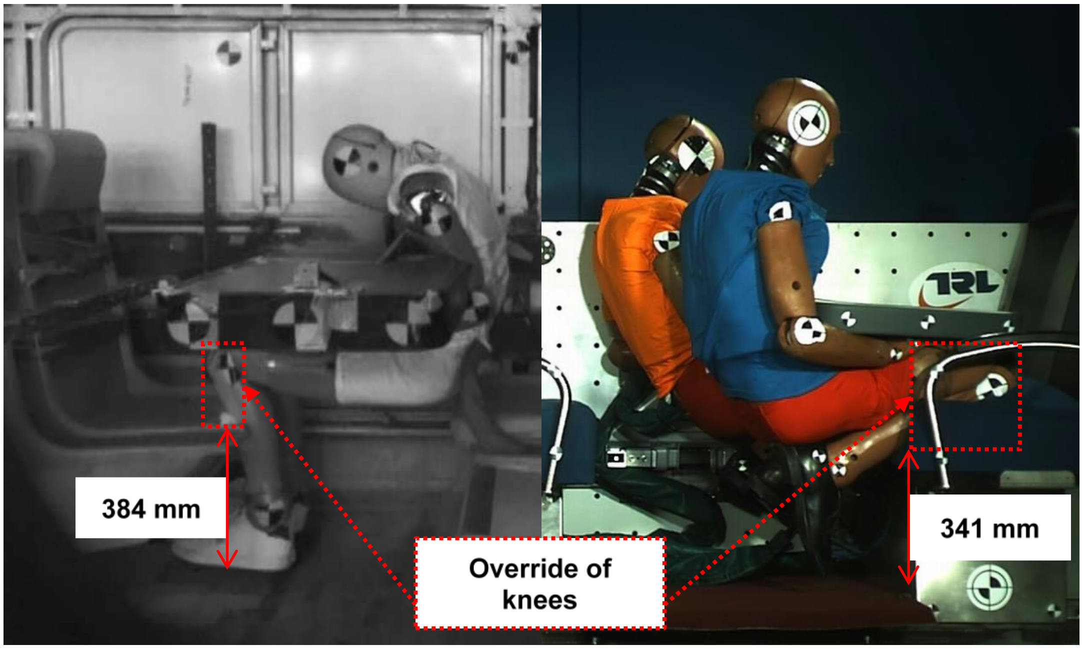
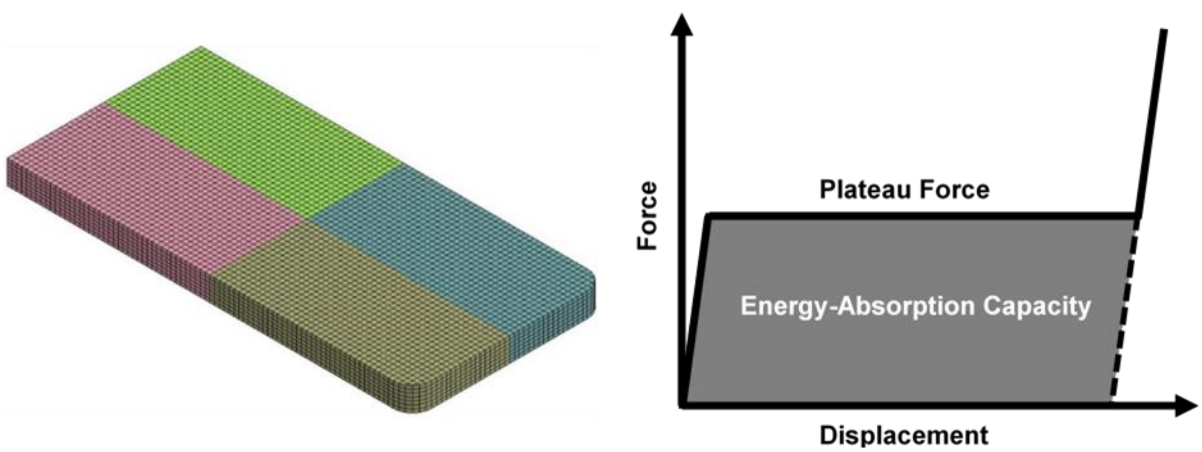


Figure 12 shows the FE model of the idealized table (left) and a diagram of the force-displacement characteristic (right). In addition to varying parameters of the seating and table configurations, the plateau force of the table was set at levels between 742 and 1798 lbf (3.3 and 8 kN). The geometry of the table is based on the FRA prototype table shown on the left of **Figure 11**; however, the thickness has been reduced to 2.5 in. (63.5 mm) to be more representative of industry-developed crashworthy table designs.

FIGURE 12
Geometry of Idealized Table FE Model (Left) and Force-Displacement Characteristic of Discrete Springs (Right)



While 8 kN was used as an upper limit for the plateau force in the parameterized FE study, it is not recommended as a design guideline for low tables that do not fully engage the ribs of the ATD.

Relationship between energy absorption and seat back spacing

Figure 13 shows the relationship between energy absorption and seat back spacing. Green markers met the dynamic test injury criteria, red markers failed one or more injury criteria, and orange markers represent FE analysis results that were close to the injury limits (within 5%) and within the realm of uncertainty inherent to the simulation.

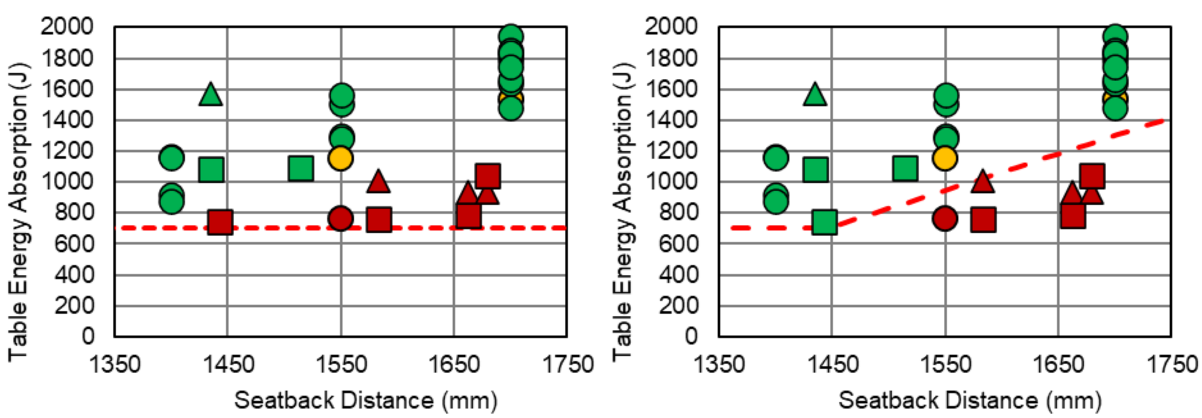
The square (wall side) and triangle (aisle side) markers represent quasi-static test results with an allowed force of 2248 lbf (10 kN). The plot on the left used the requirements from Rev. 1 of this standard, and the plot on the right used the requirements from Rev. 2 of this standard. Ideally, the energy absorption requirement (dashed red line) would have the green markers above it, which met the dynamic injury criteria. Additionally, the red markers, which did not meet the dynamic injury criteria, would ideally be below the quasi-static requirement.

However, the flat Rev. 1 (left plot) energy absorption requirement of 706.2 J did not meet this objective for crashworthy tables positioned at larger seat back spacings. Subsequently, the Rev. 2 (right plot) bilinear requirement was created to better discriminate between the tables that passed versus failed the dynamic injury requirements.

Because test results were not available from crashworthy tables that were able to meet the dynamic injury requirements for large seat back spacings (≥1550 mm), simulation results (circles) were used to estimate a relationship between seat back spacing and energy absorption. While the peak energy absorption of a table is not directly evaluated in a dynamic test, computational modeling could be used to infer the energy absorbed by the table in arresting the forward motion of an H3-RS FE model. Three levels of seat back spacing at 55.1, 61.0 and 66.9 in. (1400, 1550 and 1750 mm) were simulated. The vertical spread within the FE analysis results (circles) at each seat back spacing represents the dependence on the other table and seating configuration parameters investigated (see **Table 7**).

FIGURE 13

Table Energy Absorption vs. Seat Back Spacing with Rev. 1 Requirements (Left) and Rev. 2 Requirements (Right)



Because a linear relationship has been observed between energy absorption and seat back spacing in FE analysis of the dynamic 8g table test, Section 5.2.2.3 in Rev. 2 of the standard has been updated to specify a bilinear quasi-static energy absorption requirement. The energy absorption requirement from Rev. 1, i.e., 6250 in.-lbf (706.2 J), is maintained up to a seat back spacing of 57 in. (1448 mm). For seat back spacings above 57 in. (1448 mm) the energy absorption requirement increases according to Equation (1) in Section 5.2.2.3, which is depicted by the dashed red line in the plot on the right of **Figure 13**.

The allowable quasi-static load limit in Section 5.2.2.2 has been reduced from 10 kN to 8 kN in the case where tabletop-to-seat-cushion distance (dimension *F*) is less than 295 mm, or the table dislodges the chest rotary potentiometer, because these situations correspond to an impact where the table moves below the ribs of the H3-50M ATD. Low tables with contact forces above 8 kN have been observed to exceed abdomen injury performance limits in FE simulations with models of the H3-RS and THOR-50M ATDs. However, high tables with contact forces between 8 and 10 kN have not been observed to exceed abdomen or chest injury performance limits in FE simulations of the H3-50M, H3-RS and THOR-50M ATDs.

Appendix B: Human injury criteria

The purpose of this appendix is to summarize the selection of performance requirements with respect to their source and risk of human injury, where available.

A literature review was conducted in order to determine appropriate human injury performance requirements for blunt frontal chest and abdominal impacts. A majority of the injury assessment reference values (IARVs) for chest and abdominal injury criteria were taken from experiments addressing either seat belt or steering wheel loading to the frontal aspect of the thorax and abdomen. Unfortunately, there have been no experiments conducted using human volunteers or post-mortem human surrogates (PMHS) that appropriately characterize the impact of the edge of a workstation table with the frontal aspect of the lower chest or upper abdomen.

Injury risk functions have been developed to relate measurements of occupant response using a test dummy to the risk of injury based on the Abbreviated Injury Scale (AIS). An AIS score classifies the survivability of injuries on a scale from 1 (minor or superficial) to 6 (maximum or fatal). In 49 CFR 571.208 and other automotive safety standards, performance requirements are specified based on an associated IARV, i.e., a given percentage risk of a certain AIS score.

The performance requirements in APTA PR-CS-S-018-13 were specified to be in agreement with widely accepted requirements in automotive safety standards and GM/RT 2100 where possible. The human injury criteria in APTA PR-CS-S-018-13 are summarized in **Table 8**.

TABLE 8
Summary of Human Injury Criteria Performance Requirements in APTA PR-CS-S-018-13

Injury Criterion	Symbol	Performance Requirement	IARV	Source
Head injury criterion, 15 ms	HIC_{15}	700	P(AIS 2+) = 31%	[6]
Neck injury criterion	N_{ij}	1.0	P(AIS 3+) = 35%	[7]
Neck axial tension	F_z	4.17 kN (937 lbf)	P(AIS 3+) = 25%	[34]
Neck axial compression	F_z	−4 kN (−899 lbf)	P(AIS 3+) = 19%	[34]
Femur axial load	F_z	±10 kN (±2250 lbf)	P(AIS 2+) = 35%	[5, 6]
Chest acceleration	A_s	60g	P(AIS 3+) = 65%	[5, 6]
Chest compression	D_{max}	63 mm (H3-50M) 70 mm (THOR-50M)	P(AIS 3+) = 51% P(AIS 3+) > 82%†	[34] [7]
Abdomen compression	δ_{max}	86 mm (THOR-50M)	P(AIS 3+) = 33%	[7]

† The AIS 3+ injury risk function from Craig et al. [7] used peak chest resultant deflection instead of chest compression. Resultant deflection is greater than chest compression.

Kleinberger et al. [5] and Eppinger et al. [6] summarized the development of most of the injury criteria in 49 CFR 571.208, which is the source of many of the requirements in APTA PR-CS-S-018-13. NHTSA updated the injury risk functions for some of the injury criteria in the 2008 final notice of the New Car Assessment Program (NCAP) [34]. Craig et al. [7] published recommended injury criteria for the THOR-50M ATD which used a formulation of maximum resultant chest deflection for the THOR-50M as opposed to sternal compression, which is used for the H3-50M. Craig et al. also noted that sternal compression measurements from the H3-50M tended to underpredict the risk of AIS 3+ injury.

At the time of drafting APTA PR-CS-S-018-13, NHTSA had not published guidelines on evaluating abdomen injury from a frontal impact. In the U.K., GM/RT 2100 specified an abdomen VC performance limit of 1.98 m/s but did not provide details on an associated risk of injury. Muhlanger et al. [8] conducted a literature review and could not find abdominal frontal impact VC injury risk functions. Muhlanger et al. concluded that a 1.98 m/s abdomen VC corresponds to a 25% risk of AIS 4+ injury based on blunt side impact testing to the abdomen [8]. While drafting Rev. 2, another literature review was conducted by Volpe and found that an abdomen VC of 1.98 m/s corresponds to a 97% risk of an AIS 2+ injury and an 82% risk of an AIS 3+ injury based on frontal seat belt testing by Kent et al. [35]. Unfortunately, abdominal VC injury risk functions based on blunt impacts were not found in the literature.

Updated abdomen deflection injury criteria in Rev. 2

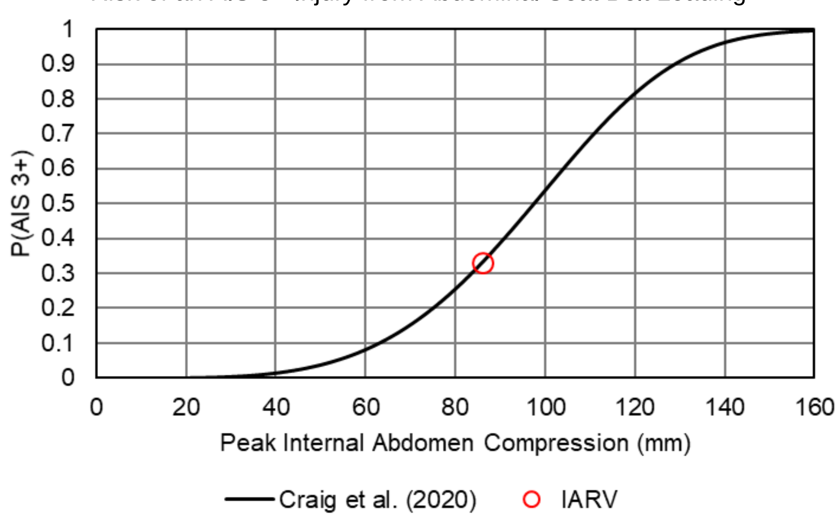
The development of the abdomen compression (δ_{max}) performance limit specified in the original and Rev. 1 of APTA PR-CS-S-018-13 is summarized by Muhlanger et al. [8] and Severson [22]. The performance limit of 67 mm references a 5% risk of an AIS 4+ injury occurring at 38% abdomen compression (A_{max}) from Rouhana et al. [36]. The original calculation of δ_{max} from A_{max} was attained using Equation (3) with a proportionality factor of 1.3 [37] and an assumed undeformed abdomen depth δ_{abd} of 229 mm.

$$\delta_{max} = \frac{A_{max} \cdot \delta_{abd}}{1.3} \tag{3}$$

However, it was later determined that (1) the proportionality factor of 1.3 was incorrect and (2) the actual undeformed depth of the H3-RS and THOR-50M is greater than 229 mm.

In 2020, Craig et al. published a report on injury criteria for the THOR-50M ATD [7]. Craig proposed an AIS 3+ curve (**Figure 14**), which was created by regression analysis on seat belt porcine test data from Kent et al. [35]. The AIS 3+ curve proposed by Craig differs slightly from the AIS 3+ curve initially proposed by Kent. Using Craig's AIS 3+ curve, the C&S working group agreed on a performance limit at 86 mm of abdomen compression corresponding to a 33% risk of an AIS 3+ injury. Unlike Equation (3) proposed by Muhlanger et al., the evaluation of peak abdomen compression in the THOR-50M ATD proposed by Craig et al. does not include a proportionality factor, which may explain why the AIS 3+ IARV is substantially higher.

FIGURE 14
Risk of an AIS 3+ Injury from Abdominal Seat Belt Loading



As of Rev. 2 of APTA PR-CS-S-018-13, the updated abdomen compression limit of 86 mm has been applied to only the abdomen test device in the THOR-50M. Based on pendulum impact testing of the abdomen test device in the H3-RS [23], the lower abdomen and upper abdomen biofidelity corridors [14] are exceeded before an internal abdomen compression of 86 mm is achieved. Because of this, the original performance limit of 67 mm from Rev. 1 of APTA PR-CS-S-018-13 is still applied to the H3-RS ATD. However, abdomen impact testing of the THOR-50M [27] has shown that the THOR-50M stays within the corridor up to an internal abdomen compression of 86 mm. The limit for the H3-RS may be increased in a later revision of APTA PR-CS-S-018-13, if the abdomen test device is updated so that it remains within the biofidelity corridor up to the increased peak abdomen compression performance requirement of 86 mm.

This difference in internal biofidelity between the abdomen test devices in the THOR-50M and H3-RS is attributed to the THOR-50M using IR-TRACC deflection sensors and the H3-RS using string potentiometers. Craig et al. noted that the high-tension upper abdomen string potentiometer in the THOR-NT (earlier version of the THOR-50M) resulted in permanent deformation of the foam inserts and tended to underestimate upper abdominal internal deflection [7]. A further discussion on the difference between the pendulum impact responses of the ATDs is provided by Eshraghi et al. [27].

Updated chest deflection injury criteria in Rev. 2

The development of the maximum chest compression (D_{max}) performance limit specified in the original and Rev. 1 APTA PR-CS-S-018-13 is summarized by Muhlanger et al. [8] and Severson [22]. Because a significant number of crashworthy table designs had not been tested at the time, the APTA C&S working group agreed on a performance limit of 63 mm, corresponding to a 33% risk of an AIS 3+ injury as defined by Eppinger et al. [6]. This performance limit was specified to harmonize with the Federal Motor Vehicle Safety Standard (FMVSS) No. 208 (49 CFR 571.208) for automotive occupant crash protection. Afterward, NHTSA updated the injury risk function in its final notice on NCAP [34] based on a reevaluation of PMHS data by Laituri et al. [38] because the original occupant risk function from Eppinger was independent of occupant age. NHTSA used a normalized age of 35 years based on the average age of the driving population. The performance limit of 63 mm corresponded to a 51% risk of an AIS 3+ injury using the injury risk function from Laituri et al [35].

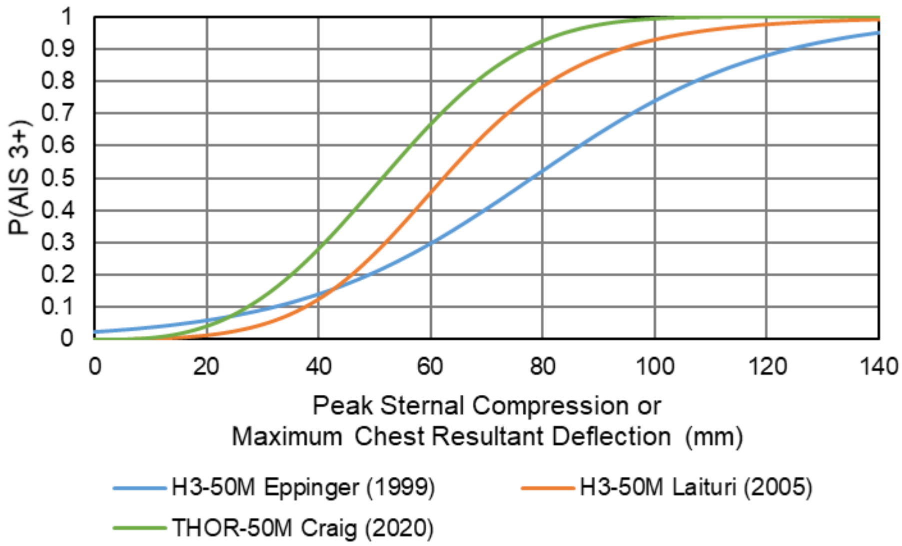
In his analysis, Laituri used a curve fit to transform from maximum percent external chest compressions ($\overline{UC}$) measured on PMHS to maximum internal chest compression (D_{max}) measured by an H3-50M. The curve fit is given in Equation (4) and is analogous to the proportionality factor described in Equation (3) for abdomen compression.

$$\overline{UC} = 0.0583 \cdot {D_{max}}^{0.4612} \quad (4)$$

While this curve fit was specifically developed for the H3-50M, the D_{max} values are scaled for injury risk functions for other Hybrid family ATDs using biomechanical scaling factors developed by Mertz et al. [39]. Similar scaling techniques have not been undertaken in applying this function to specify an injury risk function for the H3-RS or THOR-50M. While H3-50M, H3-RS and THOR-50M ATDs are based on a 50th percentile male, they feature different chest deflection sensors which would affect their external versus internal biomechanical response.

Craig et al. proposed a risk function for AIS 3+ chest injury as a function of maximum resultant deflection in the THOR-50M ATD. The risk function for the THOR-50M is expected to be included in the U.S. NCAP soon. Since maximum resultant rib deflection is greater than peak sternal compression, it is noteworthy that the injury risk functions have progressively become more conservative from 1999 to 2020. Since the THOR-50M demonstrates improved biofidelity versus the H3-50M [40], it could be expected that the injury risk function for the THOR-50M should be less conservative (shifted to the right) than the H3-50M. The risk functions for the H3-50M [6, 38] and THOR-50M [7] are shown in **Figure 15**. A similar injury risk function for the H3-RS has not been proposed in the literature.

FIGURE 15
Risk Functions of an AIS 3+ Chest Injury for the H3-50M and THOR-50M ATDs



Subsequent to Rev. 1 of APTA PR-CS-S-018-13, FRA sponsored dynamic tests of donated crashworthy table designs per Option A of APTA PR-CS-S-018-13 at TRL [24] and MGA [28]. The FRA-sponsored test results indicated that harmonization with an IARV for a restrained occupant in an automotive frontal crash accident scenario (49 CFR 571.208) was comparatively too restrictive for an unrestrained occupant in a passenger rail accident. In Rev. 2 of APTA PR-CS-S-018-13, the chest deflection performance limit was increased to 70 mm for the H3-RS and THOR-50M advanced frontal crash ATDs. The new proposed chest deflection limit for Rev. 2 of APTA PR-CS-S-018-13 is approximately midway between the original 49 CFR 571.208 chest deflection limit of 76 mm [41] and the updated limit of 63 mm [6] for the H3-50M.

The chest deflection performance requirement has not been increased for the H3-50M because the chest deflection rotary potentiometer tends to underpredict the actual chest deflection of an occupant. Eppinger et al. [6] noted that this effect was observed based on the position of a seat belt on the shoulder and pelvis of the ATD. Parent et al. [40] also reported that the THOR-50M ATD had better biofidelity than the H3-50M based on internal deflection in a blunt sternal impact. This means that, in an identical impact condition, the THOR-50M measured more internal chest deflection than the H3-50M. Lastly, Craig et al. [7] noted that automotive accident data indicated that lower rib fractures were more common than upper rib fractures oftentimes due to asymmetric loading, and these common locations for rib fractures were not near the location of the chest deflection sensor in the H3-50M.

As reported by Craig et al., the H3-50M's underprediction of internal deflection is typically due to the position of the chest deflection sensor. The rotary potentiometer (see **Figure 9**) has a central (unilateral) point of contact on the anterior side of the H3-50M between the third and fourth ribs. However, the lower chest deflection sensors in the THOR-50M have two (bilateral) attachment points on the sixth ribs, and the lower chest deflection sensors in the H3-RS have two attachment points on the fifth ribs. In the case of a table impact, the THOR-50M and H3-RS have sensors closer to the point of contact from a table (lower chest and upper abdomen), and they tend to measure higher internal deflections than the H3-50M when dynamically tested with the same table design.