RESEARCH AND DEVELOPMENT OF A SAFETY STANDARD FOR WORKSTATION TABLES IN THE UNITED STATES

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CONTENT

Summary

The US safety standard for workstation tables is presented to an international audience, such that rail operators and equipment manufacturers may better understand the research behind the requirements, the process through which the safety standard was developed, and how to demonstrate compliance.

1 Introduction

Passenger train accidents are rare, resulting in an average of less than ten fatalities per year over the last ten-year period in the United States (US). As the government agency responsible for rail safety regulations in the US, the Federal Railroad Administration (FRA) conducts accident investigations and sponsors research projects to learn from these accidents, so that, as passenger rail travel continues to grow, rail passenger fatalities and injuries will continue to go down.

A number of rail accident investigations in the US have identified safety hazards associated with thin, rigid workstation tables. Thoracic and abdominal injuries caused by passenger impacts with tables during train accidents have been cited as the cause of numerous serious and sometimes fatal injuries. The FRA has sponsored research to better understand the nature of passenger impacts with workstation tables during train accidents, and to propose solutions to mitigate the consequences of table impacts. This research has led to collaboration with the American Public Transportation Association (APTA) and other industry partners to develop a safety standard for fixed workstation tables that will ensure a minimum level of table crashworthiness.

The APTA safety standard for tables (APTA-SS-C&S-018 – Fixed Workstation Tables in Passenger Rail Cars [1]) applies to workstation tables at revenue seats in coach and cab cars, in all classes of passenger seating. The standard provides detailed design requirements with regard to attachment strength, geometry, operational strength, crashworthiness, and fire safety. The standard defines the appropriate test conditions, test measurements, and performance requirements, and provides guidance on how to demonstrate compliance with the requirements.

The APTA standard was developed over the course of several years with input from the FRA, the Volpe National Transportation Systems Center (Volpe Center), APTA, rail operators, rail equipment suppliers, rail consultants, and others. The collaborative process was based on a review of accident investigations and subsequent research to develop and evaluate a prototype table. The final version of the standard underwent several review-and-comment periods, achieved consensus among the various stakeholders, and underwent balloting among APTA members, prior to its adoption in 2013.

The US safety standard for workstation tables is presented to an international audience, such that rail operators and equipment manufacturers may better understand the research behind the requirements, the process through which the safety standard was developed, and how to demonstrate compliance.

2 Background

2.1 Accident Investigations

The FRA sponsors Volpe Center investigations of train accidents in which fatalities or several serious injuries occur. The Volpe Center has participated in about fifteen accident investigations since 1999. The primary objectives of these investigations are to estimate the initial accident conditions and the sequence of events during the accident, and to determine the causal mechanisms of injuries and fatalities. Generally, the team travels to the site of the accident within 24 hours of the accident. Information is gathered from the interior and exterior of the rail cars – documenting observed damage and indications of occupant impacts – and from the track and wayside. Emergency responders are interviewed to collect information gleaned during the rescue effort. Passengers are interviewed to document their recollections of the sequence of events during the accident, as well as specific injuries that were incurred. The collective data are used to determine causal mechanisms of injury during an accident. Subsequently, the FRA may sponsor research to develop strategies to mitigate particular mechanisms that lead to severe injuries or fatalities in train accidents. Ultimately, this information is used to evaluate and improve the effectiveness of current crashworthiness and emergency preparedness regulations and safety standards.

It is noteworthy that the National Transportation Safety Board (NTSB) conducts its own train accident investigations for the US Government. The NTSB is tasked by the US Congress to investigate accidents in all modes of transportation. Its purpose is to determine the cause of an accident, and to make recommendations to prevent similar accidents and minimize their consequences. The NTSB investigates many more rail accidents than the Volpe team. When investigating the same accident, there is communication and cooperation between the two agencies.

Workstation tables were identified as the cause of severe abdominal injuries, some of which were fatal, in some of the FRA/Volpe accident investigations. These accidents occurred in Placentia, California, on April 23, 2002 [2, 3, 4]; Glendale, California, on January 25, 2005 [5]; and Chatsworth, California, on September 12, 2008 [6, 7]. Workstation tables also caused serious abdominal injuries during train accidents in Intercession City, FL in November, 1993 [8]; Burbank, CA, in January, 2003 [9]; in Mebane, North Carolina, in May, 2010; and Amsterdam in April, 2012 [10]. The Volpe Center was not part of these accident investigations, so details are not included in this paper.

The three aforementioned accidents in California each involved a multilevel commuter train. Each of these multilevel cars had fixed workstation tables that were mounted to the carbody sidewall with an L-bracket and supported vertically by a floor pedestal. The tables were about an inch thick, constructed of plywood with a melamine cover on the top and bottom. During an accident, the relatively thin, rigid table top can penetrate a passenger's abdomen, resulting in large concentrated abdominal loads. In some locations, the tables had detached from the floor and wall mountings. In other locations, where occupants were known to be seated, the tables remained fastened to the rail car with very minor or no displacement, causing virtually all of the occupant's kinetic energy to be absorbed by the occupant's body. Ideally, the table and/or its attachments would deform and share in the absorption of kinetic energy. Rather than present a collision safety hazard, tables designed to absorb energy can enhance collision safety, by serving to compartmentalize passengers, i.e., to arrest the occupant's motion before large velocities are attained with respect to the vehicle interior, and to prevent contact with passengers seated in facing seats.

The accident in Placentia occurred when a freight train impacted a standing commuter train, resulting in two fatalities. Both of these fatally injured people were determined to have been seated at workstation tables, facing the direction of travel. Autopsy results indicated severe blunt trauma impact injuries to the chest and abdomen, including ruptured/lacerated spleens and livers, fractured ribs, and fractured vertebrae. The accident in Glendale resulted in eleven fatalities, all of which were attributed to loss of survival space. Some interviewed passengers were injured when they impacted tables, but these injuries were not considered to be life-threatening. Injuries due to confirmed table impacts in the Glendale accident include liver contusions, rib and spinal fractures. The accident in Chatsworth resulted in 25 fatalities; 23 of which were due to loss of survival space. As in the Glendale accident, several Chatsworth passengers incurred serious, though nonfatal, abdominal injuries due to confirmed table impacts, including multiple rib fractures, lacerated liver and spleen, and a mesenteric tear. The NTSB report on the Chatsworth accident also noted the risk of serious abdominal injury due to occupant impacts with the workstation tables.

Additional details about the Chatsworth accident were provided in the legal settlement [11]. Regarding passengers seated at tables, the settlement states that, “Almost every table passenger sustained and suffered horrible abdominal injuries that cannot be medically resolved. Almost all of one's vital organs were implicated for those who sat at the tables.” The settlement awarded $200,000,000 to the plaintiffs, which was the maximum statuary monetary award allowed. About $75 million in claims was paid to families of the deceased passengers. Most of the fatalities were due to loss of survival space. An additional $125 million in claims was paid to the injured passengers. Most of the nonfatal injuries were due to secondary impacts. A mere fraction of this money could be well spent to improve table crashworthiness.

The Placentia accident report published by NTSB noted that there were no FRA regulations in place to address the crashworthiness of workstation tables in trains. This accident led the FRA to direct the Volpe Center to initiate research into the crashworthiness of existing workstation tables, and to develop lumped-mass computer models incorporating simulated anthropomorphic test devices (ATDs) that were able to approximate the behavior of the existing tables during accidents and the resulting injuries incurred by passengers. Upon validating these models against available accident data, subsequent computer models were developed with modified table properties, such as geometry and force versus deflection behavior, which minimized the abdominal injury associated with table impacts under similar collision conditions. Based on desirable table crush and energy absorption behavior, a prototype table design was developed and tested [12, 13, 14, 15]. The intention of the prototype table was to demonstrate the effectiveness of a crashworthy table, which was designed to limit the load imparted to an occupant by distributing the load over a larger area and by absorbing a significant portion of the occupant’s kinetic energy through material deformation. This research formed the technical basis of the APTA workstation table standard described in this paper.

2.2 US regulations and safety standards

In the US, a combination of federal regulations and industry safety standards provide a high level of protection against the consequences of accidents. Included in the federal regulations are vehicle structural requirements that define minimum strength requirements. These requirements are supplemented with industry standards that provide additional requirements for seat crashworthiness and attachment strength of interior fittings. The standards provide additional guidance on testing conditions, performance requirements and documentation requirements.

The APTA seat standard [16], which was developed through the APTA Passenger Rail Equipment Safety Standards task force, was initially authorized in 1999. It defines minimum crashworthiness requirements for passenger seats. The standard requires sled testing with instrumented ATDs to demonstrate that seats remain attached during a simulated collision, measured ATD injury assessment reference values (IARVs) are below maximum allowable thresholds, and ATDs remain compartmentalized between rows of seats. The crash pulse, or deceleration time history, for seat tests is specified as a triangular pulse, with a peak at 8Gs and a duration of 250 milliseconds, as shown in Figure 1. While actual crash pulses will vary due to vehicle mass, speed, and strength, the test crash pulse is intended to represent a moderate speed, head-on collision with a similar train, in which the strength of the occupied volume is exceeded. Collision dynamics models based on data from accident investigations indicate that the 8G pulse is representative of a moderately severe accident involving some crush of the occupied volume [16]. The APTA table standard is very similar to the seat standard, using the same test conditions and performance requirements, with additional criteria for abdominal injury that may occur with table impacts.

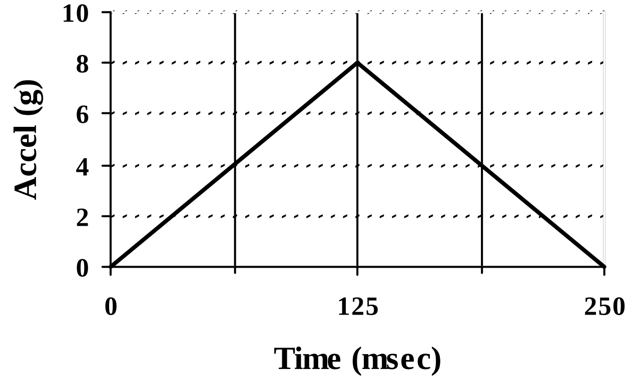

Figure 1. An 8g Peak, 250 millisecond Triangular Acceleration Pulse

Until recently, the only requirements for workstation tables were minimum attachment strength specifications under inertial loading conditions. Accident investigations revealed a need for improved workstation tables that would be less hazardous in a collision. FRA and Volpe began conducting research and developing a prototype of an energy-absorbing table. Independently, rail operators such as Southern California Regional Rail Authority (SCRRA) and North Carolina Department of Transportation (NCDOT) began to ask for a standard to provide guidance in specifying crashworthy tables for rail car procurements, based on their own initiatives to improve collision safety. The accident history and interest in improved public safety led industry stakeholders to pursue the development of an industry safety standard for workstation tables.

3 Workstation Table Research

A multi-step research methodology has been applied in the development of strategies to minimize hazards of table impacts, as depicted in the flow chart in Figure 2. The details of steps one/ two, three/four, five, and six are described in references 2, 3, 12, and 13/14, respectively.

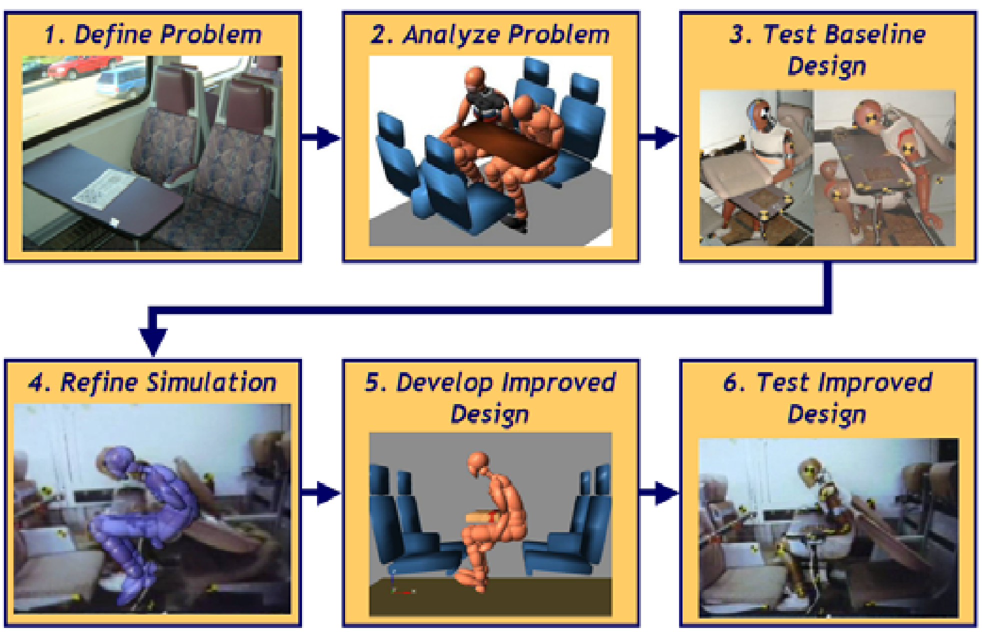

Figure 2. Flow Chart of Workstation Table Research Methodology

The abdominal injuries observed in accident investigations were caused by impacts with thin, rigid workstation tables, which resulted in concentrated loads to the upper abdomen. To analyze the problem, computer models were developed with MADYMO 3D [18] using existing tables as a baseline. The models were refined and validated against test and accident data. A prototype design was developed and tested, based on the following four design requirements, which were primarily focused on crashworthiness. Functional requirements were also included (see Reference 12 for additional information).

First, the table must compartmentalize the occupants. Research has shown that compartmentalization is an effective strategy in minimizing injuries due to secondary impacts [19]. The secondary impact velocity generally increases with distance traveled with respect to the vehicle interior during a train collision. Judiciously designed tables can minimize the distance traveled prior to secondary impact, thus limiting the kinetic energy that must be absorbed by the impact. Tables must also remain attached to the carbody to maintain occupant compartmentalization.

Second, the table must be designed to limit the peak contact force and distribute the load over a large area. The thickness of the table should be as large as possible within available space constraints, but no less than two inches. A thicker table increases the likelihood of engaging either the pelvis or the rib cage for a wide range of occupant sizes, which could minimize the injury to the vulnerable internal organs.

Third, forces and decelerations experienced by a 50th percentile ATD during an 8G sled test must not exceed maximum allowable IARVs for the head, neck, chest, abdomen, and femurs. Table 1 lists the maximum allowable injury criteria for the design of the prototype table.

Fourth, the tables must not inhibit occupant egress following a collision. Passengers seated on the opposing side of the impacted table cannot become trapped or pinned due to excessive deformation or displacement of the table.

Table 1. Maximum allowable injury criteria

Injury Criteria	Maximum IARV	Units
HIC15	700	no units
Nij	1.0	no units
Neck Tension	4,170	N
Chest Acceleration	60	G
Chest Compression	67	mm
Chest V*C	1.0	m/s
Abdominal Compression	75	mm
Abdominal Force	6,500	N
Abdominal V*C	1.5	m/s

In addition to the previous design requirements, the following parameters, which were based on preliminary computer modeling, were used to guide the design of the improved workstation table:

The minimum force necessary to cause permanent table edge crush is 750 lbf (3.3kN).

The maximum force experienced by the occupant caused by impact with the table is 2,200 lbf (9.8 kN).

These force parameters were used to develop an idealized force/crush curve for an individual seat position at the table (see Figure 3). A table with this force/crush characteristic meets the design requirements defined above in computer models and was used to guide the design process.

Figure 3. The Ideal Design Table Load/Crush Curve for a Single Seated Position

A schematic of the prototype table is shown in Figure 4. The cantilevered table was designed to be fastened to the carbody side wall, per the design requirements. The dimensions of the table thickness, length, and width, were 4 in., 40 in., and 20in., respectively.

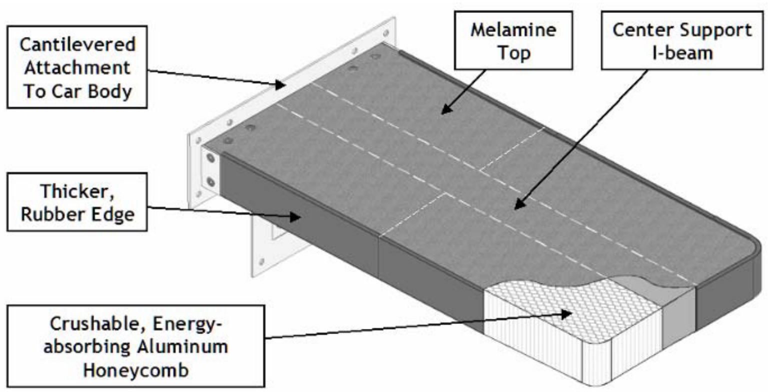

Figure 4. Schematic of Prototype Workstation Table

The prototype table was tested in a 31-mph full-scale train-to-train impact test using passenger rail cars that incorporated energy absorbing crush zones at the ends of each car [14, 15]. The deceleration time-history of the train was more severe than the 8G, 250 ms deceleration time-history for which the prototype table was designed. Two table experiments were conducted onboard the train using two different ATDs (identified as THOR [20] and H3RS [21]). Both ATDs included instrumentation to assess abdominal injuries. Compared with injury results from a similar full-scale impact test using the baseline table [12], the abdominal injury criteria were significantly reduced for both ATDs. Pre- and post-test photos of the prototype table test using the THOR ATD are presented in Figure 5. The injury results from the baseline and prototype table tests are presented in Table 2. The injury criteria from each test are averaged from the two ATDs. The shaded boxes in the table indicate that the measured injury criteria exceeded the design criteria. There is improvement in all of the injury criteria for the prototype table. More importantly, the abdominal injury criteria from the prototype table test were below its design requirements.

Figure 5.Pre- and Post-Test Photos of Prototype Table Test with THOR ATD

Table 2. Comparison of Injury Results for Baseline and Prototype Table Tests

Criteria	Prototype Table Design Requirements*	Baseline Table Test (Average)	Prototype Table Test (Average)
Upper Abdomen Compression, mm	70	105	57.5
Upper Abdomen V*C, m/s	1.25	1.38	1.05
Chest g	30	60	25
HIC15	700	374	116
Nij	1.0	0.58	0.31
Neck Tension, lbf	937	798	315
Femur Load, lbf	2,250	1,017	1,025

*The design requirements reported in this table were modified slightly from the values reported in Reference 12 and Table 1, as more information was collected on acceptable human tolerance thresholds for abdominal injury.

4 Details of U.S. Workstation Table Standard

The results of the prototype table testing led to the initiation of the development of the APTA table standard. The table standard was written to parallel the APTA seat standard. The standard development was a collaborative process among the stakeholders, including FRA, Volpe Center, APTA, rail equipment manufacturers, and industry consultants. Research results were presented at industry working group meetings and consensus was developed about the need for a safety standard. Several iterations of the draft standard were prepared by the Volpe Center and reviewed by the stakeholders until all issues were resolved.

The purpose of the table standard is to define requirements for workstation tables that result in reduced injuries and fatalities due to table impacts during passenger rail accidents. The standard applies to fixed workstation tables positioned at revenue seats in coach and cab cars, including electrical multiple units (EMUs) and diesel multiple units

(DMUs), and in all classes of coach seating, i.e. business class, first class, economy, and coach. The standard does not apply to fold-down seatback tables or other non-fixed tables, or to tables in sleeping cars, dining cars, lounge cars or food service cars.

The table standard specifies attachment strength requirements consistent with federal regulations [22], namely that the table must withstand the load associated with the individually applied accelerations of 8g longitudinal, 4g vertical, and 4g lateral, acting on the mass of the table. Geometry requirements are specified to minimize points of entrapment and concentrated loading points (associated with sharp radii). Vertical and horizontal quasi-static proof load requirements are also specified to demonstrate that the operational loads do not cause damage to the table that would prevent it from functioning as intended in a collision. The dynamic test requirements, described below in detail, form the crux of the safety standard.

4.1 Dynamic Test Conditions

Dynamic sled testing is specified to demonstrate that a workstation table achieves four main objectives:

- The table effectively absorbs kinetic energy, while minimizing the contact force between the occupants and the table.
- The table remains attached to the test sled.
- The table effectively compartmentalizes the occupants.
- The table effectively minimizes human injury.

In preparation for testing, a workstation table and passenger seat(s) are mounted to a simulated rail carbody or a rigid test sled in the nominal relative positions for the intended rail service. Instrumented anthropomorphic test devices (ATDs), representative of 50th-percentile adult males, shall be positioned to face the direction of travel, such that all forward-facing seats are simultaneously occupied by an ATD for each test. The ATDs shall be Test devices for Human Occupant Restraint (THORs)[20], or Hybrid III Rail Safety ATDs (H3RSs) [21], which are capable of measuring compression of the abdomen and chest, and corresponding rates of compression, and for calculating the injury criteria described below.

Standard Hybrid III ATDs are specified in US federal regulations for automobile crashworthiness testing. Consequently, these ATDs are widely available at most test facilities in the US. Unfortunately, the standard ATDs do not have the necessary abdominal instrumentation to capture the effects of the table impact. The THOR and H3RS ATDs have the necessary abdominal instrumentation, but these ATDs are not yet widely available because they are not currently required in US automobile regulation. There are plans to incorporate the use of the THOR ATD into the US automobile regulations in the next few years. When this occurs, more THOR ATDs will be produced and they will be available at most US test labs. In the interim period, accommodations have been made in the table standard to provide alternatives to the table manufacturer.

In lieu of a THOR or H3RS, standard HIII ATDs may be used in dynamic table testing to demonstrate that the table meets all performance requirements, except for the two abdominal injury criteria. In this case, a validated computer model, developed using a commercial computer code such as MADYMO [18], shall be used to demonstrate that the table can also meet the abdominal injury criteria under the same test conditions.

The test sled shall be subjected to an 8G, 250 ms crash pulse, as shown above in Figure 1. The measured crash pulse shall comply with the five-step evaluation process established in SAE AS8049 Revision A, Appendix A [23], to determine that the actual pulse is within accepted tolerance parameters. If a computer model is used instead of an advanced ATD to evaluate abdominal injuries, then the measured acceleration time history from the test sled shall be used for the crash pulse in the model.

4.2 Measurement and Documentation Requirements

The following data shall be obtained for each ATD during the test, in accordance with the data measurement procedures established SAE J211/1 [24]:

- triaxial head acceleration-time history
- triaxial chest acceleration-time history
- axial left and right femur force-time history
- upper neck extension/flexion bending moment, M_y time history
- upper neck axial force, F_z time history
- upper neck shear force, F_x time history
- chest compression-time history
- abdominal compression-time history
- longitudinal acceleration-time history of the test sled
- triaxial load cell force-time history, if load cells are used to measure reaction loads

The following measurements shall be taken before the test (pre-test). These pre-test measurements are needed to establish the baseline against which potential configuration modification allowances are evaluated, as described in section 4.3.2:

- Longitudinal distance (in a horizontal plane) between the front edge of the tabletop and the seat back on the side of the ATDs (depicted as measurement “A” in Figure 6).
- Vertical distance between top of tabletop and the highest point on seat bottom cushion (depicted as measurement “B” in Figure 6). If a facing seat is not used, then the measurement may be taken on the launch seat, before the ATD is placed in the seat.

The following measurement shall be taken post-test:

- Longitudinal distance (in a horizontal plane) between the front edge of the tabletop and the seat back on the side opposite the ATDs (depicted as measurement “C” in Figure 6). If a facing seat is not used, then measurement “C” shall be calculated using the theoretical position of the facing seat.

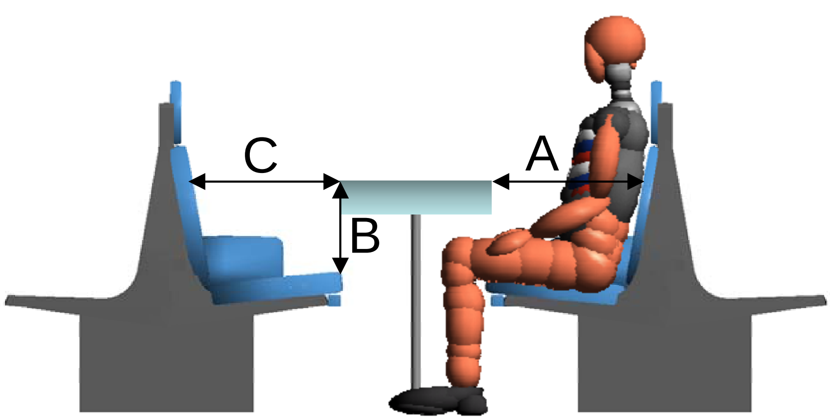

Figure 6. Schematic Depicting Pre- and Post-Test Measurements

The following injury criteria shall be computed for each ATD:

- head injury criterion (HIC15)
- 3ms chest Gs
- axial femur load
- upper neck axial tension/compression loads
- neck injury criterion (Nij)
- chest compression
- chest viscous criterion (VC)
- abdominal compression
- abdominal viscous criterion (VC)

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

The test shall be captured using high-speed cameras providing an overhead view and a side 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, as well as close-up photographs of the seats and tables and their attachments to document any damage.

4.3 Performance Requirements

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

1. The table and any table components must remain attached to the test fixture or simulated rail car structure.
2. The crush of the table shall not result in any exposed sharp edges with which an occupant would be at risk of coming into contact; nor spaces capable of entrapping an occupant during a rail accident.
3. Any table components for which the material yield strength has been exceeded shall display post-yield plasticity.
4. The table shall not penetrate the survival space reserved for occupants in the facing seat, where applicable, so as not to entrap the facing passengers or prevent egress. The survival space, as depicted by measurement “C” in Figure 6 shall not be less than 15 in., as measured post-test (theoretical location if facing seat is not used in actual test).
5. The ATDs shall be compartmentalized, as defined in the definitions at the end of this document.
6. All injury measurements must meet the following criteria (which are defined in the standard):
    - head injury criterion, HIC15, shall be less than 700;
    - neck injury criterion, Nij, shall be less than 1.0;
    - neck axial tension, F_z, shall be less than 938 lbf (4170 N);
    - neck axial compression, F_z, shall be less than 899 lbf (4000 N);
    - chest deceleration shall be less than 60 G over a 3ms clip;
    - chest compression shall be less than 2.5 in. (63 mm);
    - chest viscous criterion shall be less than 1.0 m/s;
    - abdominal compression shall be less than 2.6 in. (67 mm);
    - abdominal viscous criterion shall be less than 1.98 m/s; and
    - axial femur load shall be less than 2250 lbf (10,000 N).

4.3.1 Requirements for Validated Computer Model

If a computer model is used to demonstrate compliance with the requirements for abdominal compression and abdominal viscous criteria, then the computer modeling results will be considered to be valid if all of the following requirements are met:

- The modeling results for all injury measurements for the head, neck, chest and femur are below the maximum threshold values and also within ±20 percent of the comparable injury criteria measurements obtained from the sled test.
- Measurement "C" (depicted in Figure 6 above) taken from the model shall be within ±20 percent of the physical measurement taken post-test. If a facing seat is not used, then measurement "C" shall be calculated using the theoretical position of the facing seat.

4.3.2 Requirements to Avoid Retesting for Similar Table

If a structurally identical table design had been tested in a specific configuration and met all the requirements of this standard, it does not need to be retested for a different installation configuration if all of the parameter modifications are within the defined acceptable tolerance range below:

- Longitudinal distance (in a horizontal plane) between the front edge of the tabletop and the seat back (depicted as measurement "A" in Figure 6): +1/-3 in.; and
- Vertical distance between top of tabletop and the highest point on seat bottom cushion (depicted as measurement "B" in Figure 6): ±1 in.

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 had been tested and met all the requirements of this standard, it does not need to be retested if geometry changes are within the defined acceptable tolerance range below:

- Tabletop length: +1/-3 in.; and
- Tabletop width: +3/-0in. (see schematic in Figure 7).

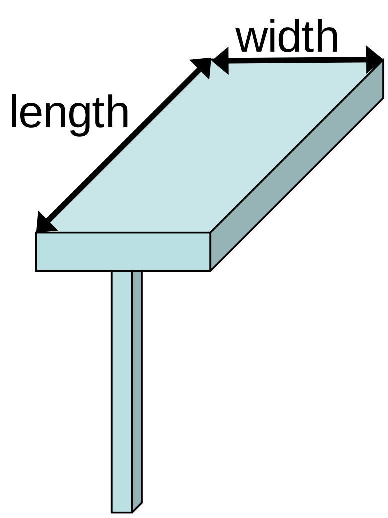

Figure 7. Schematic of Tabletop Geometry Definitions

5 Discussion

A significant challenge in developing the table standard was selecting a methodology for assessing abdominal injury, given that ATDs with abdominal instrumentation are not in abundant supply. During development and testing of the prototype table, different test conditions and performance requirements were considered and evaluated. Options included a quasi-static loading test with an energy absorption requirement, a dynamic pendulum test with a mass deceleration requirement, an 8G sled test using standard ATDs with injury criteria requirements, and an 8G sled test using advanced ATDs instrumented with abdominal transducers, with corresponding injury criteria requirements.

The quasi-static loading test was desirable for its simplicity, but it is not a dynamic event. There were concerns that a quasi-static test would not capture loading rate sensitivities associated with some materials. Also, sufficient research results were not available to correlate a maximum force and quantity of energy absorbed with abdominal injury. The dynamic pendulum test was desirable for its dynamic impact, but again, research to correlate deceleration of a mass and abdominal injury was lacking. The 8G sled test with an instrumented ATD was strongly preferred because it represents a realistic collision scenario, and it can be used to assess occupant compartmentalization, table attachment, and occupant injury. To account for the current limited availability of the THOR and H3RS ATDs, a provision was added to the standard to accept abdominal injury results from a validated computer model, such as MADYMO, in lieu of testing with an advanced ATD. The computer model must be validated with sled test data using a standard HIII ATD, per the requirements specified in the table standard. This approach allows some flexibility for the table manufacturer, until advanced ATDs are more readily available.

During the development of the APTA table standard, GM/RT2100, Requirements for Rail Vehicle Structures, Issue 4 [25], was released in the United Kingdom (UK), which includes crashworthiness requirements for workstation tables used in passenger trains in the UK. There are many similarities between the US and UK standards, as well as some differences. Both standards specify attachment requirements based on inertial loading, dynamic sled tests with instrumented ATDs, and the same vertical and horizontal quasi-static proof loads.

The most notable differences between the two standards are the dynamic test conditions and the inertial load requirements. The UK standard specifies that the deceleration time history for the test sled must fall within a defined upper and lower bound, whereas the US standard specifies that the test pulse must be above the specified minimum crash pulse. The change in velocity for each deceleration time history can be computed as a means to compare the severity of the different crash pulses. The change in velocity for the upper and lower bound in the UK standard is 29.6 and 9.9 MPH (47.6 and 15.9 KPH), respectively, an average of 19.8 MPH (31.9 KPH). The average change in velocity for the upper and lower bound in the UK standard is slightly lower than the change in velocity of 22 MPH (35.4 KPH) for the US standard. With improved testing techniques, however, test facilities can now achieve crash pulses that closely follow the lower bound, resulting in a significant disparity in pulse severity between the two standards.

Both standards specify inertial load requirements that tables and other interior fixtures must withstand. The UK standard specifies inertial loading equivalent to 5G longitudinal, 1G lateral, and 3G vertical, acting on the mass of the fixture. The US standard specifies inertial loading equivalent to 8G longitudinal, 4G lateral, and 4G vertical, acting on the mass of the fixture. The inertial load requirements in the UK standard are based on vehicle structural requirements specified in Euronorm (EN) standards. The inertial load requirements in the US standard are the same as the requirements in the US Code of Federal Regulations [22], which are based on the collision behavior of conventional US rail equipment in a moderately severe impact. Both load requirements are reasonable, given that they are both based on the collision behavior of the equipment in which the tables will be installed.

Most of the injury criteria for the head, neck, chest, abdomen, and femurs are identical, or very similar, though the UK standard specifies a number of additional injury criteria. Where the injury criteria differ between the two standards, the GM/RT 2100 standard is generally more conservative, i.e., restrictive, than the APTA standard. Given that the 5G lower bound for the GM/RT crash pulse is less severe the 8G APTA crash pulse, it can be argued that the level of safety provided by each standard is consistent.

Both standards specify the use of 50th percentile ATDs that can measure abdominal loads for injury assessment. The UK standard also specifies a dynamic sled test with a 95th percentile ATD for assessing table structural integrity and attachment. The US standard does not require a similar test with a 95th percentile ATD.

Efforts have been made to harmonize the UK and US table standards to minimize the need for manufacturers to develop substantially different tables for different rail markets. The two standards are not identical, but they both offer a similar approach, and it can be argued that they both provide a similar level of safety.

6 Conclusions

This paper describes accident investigations that provided the motivation for creation of a US workstation table safety standard, US research to develop a prototype table, the process used to develop a US table standard, and the detailed requirements contained in the standard. The US and UK table standards are also compared and contrasted. Table tests comparing an existing baseline table and a prototype of a crashworthy table demonstrate that a significant reduction in injuries due to table impacts is possible.

The table research and development, and the rationale behind the requirements in the US standard, are offered such that they may be useful to table manufacturers when developing tables that comply with the requirements in the US standard, and for rail operators when specifying technical requirements for crashworthy tables.

7 Acknowledgements

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