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## ABSTRACT

Current anthropomorphic test device (ATD) positioning procedures for drivers and front-seat passengers place the crash dummy within the vehicle by reference to the seat track. Midsize-male ATDs are placed at the center of the fore-aft seat track adjustment range, while small-female and large-male ATDs are placed at the front and rear of the seat track, respectively. Research on occupant positioning at UMTRI led to the development of a new ATD positioning procedure that places the ATDs at positions more representative of the driving positions of people who match the ATD's body dimensions. This paper presents a revised version of the UMTRI ATD positioning procedure. The changes to the procedure improve the ease and repeatability of ATD positioning while preserving the accuracy of the resulting ATD positions with respect to the driving positions of people matching the ATD anthropometry.

## INTRODUCTION

U.S. Federal Motor Vehicle Safety Standard (FMVSS) 208 specifies that the midsize male crash dummy is to be tested with the seat positioned at the middle of the fore-aft adjustment range. Recent revisions to FMVSS 208 specify tests with the small female ATD positioned at the forward most seat position. Since there are no requirements on where the front and rear of the seat track must be located with respect to the vehicle interior components, the location of these seat track reference points varies substantially with respect to the steering wheel and pedals across vehicles. Research has demonstrated that these positions are inconsistently related to the distribution of actual driver positions in vehicles.

Researchers at UMTRI have conducted extensive studies over the past decade examining the postures and positions of automobile drivers and passengers. The postures of hundreds of drivers were measured in dozens of vehicles, leading to the development of statistical models that describe the distribution of driver seat positions and eye locations (1-3). Using the same human-posture database and similar methods, a model was developed to predict the distribution of chest-to-steering-wheel clearances (4).

Recognizing the importance of occupant positioning for restraint system performance, Manary et al. (5) compared the midtrack ATD position with the actual driver-selected seat positions of midsize men. Although the ATD used for frontal impact testing does not have a measurable erect standing height (stature), the dimensions of the ATD are based on men who have a stature of 1753 mm. Using a regression analysis, Manary et al. calculated the average seat positions of drivers who are 1753 mm tall in 26 vehicles. On average, men that size sat with their seats 45.5 mm rearward of the midtrack position. More importantly, the offset varied widely across vehicles, indicating that the midtrack position was not only an inaccurate predictor of midsize male sitting position, but also inconsistent across vehicles.

Similar conclusions were reached for small women and large men. The corresponding small female and large male ATDs are usually positioned at the front and rear of the seat track, respectively. The most recent modification to FMVSS 208 calls for testing the small female ATD at the full-forward seat position. On average, women matching the reference stature of the small female ATD sit 45.2 mm rearward of the front of the seat track. However, as with the midtrack position, there are large differences between vehicles, indicating that the front of the seat track is a poor predictor of the seating positions of small women. The best correspondence between driver and ATD positions was at the rear of the seat track. The expected seat position for men who are 1870 mm tall (the reference stature for the large male ATD) was within 6 mm of the rear of the seat track, averaged across 26 vehicles. Once again, however, there were large differences across vehicles.

Overall, the middle and ends of vehicle seat tracks were found to be poor predictors of the actual locations of drivers the size of the ATDs commonly used in testing. The research also demonstrated that the current method for posturing the ATD torso (setting the seatback recline angle) is inconsistent with human occupant postures. In seats with adjustable seatback angles, the seatback angles selected by drivers are unrelated to the manufacturer's specified (design) seatback angle. The driver posture data also show that the overall orientation of the driver's torso, measured by the angle with respect to vertical of a sideview line from hip to eye, is not substantially related to driver stature or to vehicle type (sports car, sedan, minivan, SUV, etc.). Hence, the most representative way to position ATD torsos is to set the same hip-to-eye angle for all ATDs in all vehicles. The current procedures, which place the ATD in the seat at the manufacturer's specified seatback angle, introduce arbitrary variability into the ATD positioning procedure. As with seat position, testing the ATDs at positions and postures that are not representative results in inconsistent assessments of restraint system performance across vehicles.

These findings were used to develop a statistical model and basic ATD positioning procedure that produces more representative ATD positions. The UMTRI ATD Positioning Model was presented as a preliminary proposal to stimulate further research and discussion on the issues involved in ATD positioning. Working with the Insurance Institute for Highway Safety (IIHS), UMTRI researchers have improved the ATD positioning model, simplifying the implementation and fleshing out many details that were not addressed in the original model development. This paper presents the revised UMTRI ATD Positioning Procedure (ATDPP).

## UMTRI ATD POSITIONING PROCEDURE

### Original Method

The model presented by Manary et al. (5) was based directly on the UMTRI Seating Accommodation Model (SAM), which predicts the distribution of driver-selected seat position aft of the accelerator pedal (2). Several steps were taken to adapt SAM for ATD positioning.

- The fore-aft reference point was changed from a point on the accelerator pedal to the center of the front face of the steering wheel. The original reference point, the Ball of Foot (BOF), required measurements with the H-point manikin using a procedure different from the one normally used for ATD positioning.

- SAM was reconfigured to use as inputs only values that were standard SAE interior dimensions defined in SAE J1100 (6). At the time, there was no SAE dimension for the fore-aft distance from the BOF to the center of the steering wheel, but there was a defined fore-aft dimension (L11) from Accelerator Heel Point (AHP) to steering wheel center. Under the assumption that these dimensions would be available from the manufacturer for most vehicles, the model was configured to take the SAE dimensions L11, H30 (seat height), and L27 (seat cushion angle) as inputs.

- SAM did not include consideration of driver torso recline. Using other UMTRI data from drivers in vehicles, a representative H-point-to-Head-CG angle of 12 degrees aft of vertical was established. This provides a torso angle that is close to the average torso posture of drivers in all types of passenger vehicles.

### Revised Method

The original UMTRI ATD positioning model was presented in outline form, without many of the supporting steps required for implementation. The revised ATD positioning method was developed in cooperation with researchers and technicians at the Insurance Institute for Highway Safety, who used the procedure to position ATDs in a range of vehicles. The new method is documented in the appendix. There are, however, many important parts of the ATD positioning procedure that are included by reference only. For example, the H-point measurement procedures and ATD hand/arm positioning steps do not differ from existing procedures, and hence are not included in the appendix. Some additional details and contingencies are needed to create a complete procedure; nonetheless, the major elements are all in place.

The major changes since the original formulation of the ATD positioning procedure are:

1. The new procedure uses a newly defined reference point on the accelerator pedal as the fore-aft reference. The pedal reference point (PRP) is a point on the undepressed pedal that lies 200 mm from the heel rest surface along a tangent to the accelerator pedal (see Figure 1 in the appendix). Analyses at UMTRI have shown that the fore-aft location of the PRP is generally within a few millimeters of the BOF used in SAM. The PRP can be determined using a simple ruler, or can be located more precisely by digitizing the pedal and floor surfaces with a coordinate measurement machine and locating the PRP in CAD.

2. The new procedures use the same procedures for locating the seat H-point as are specified in the current FMVSS. In the new UMTRI procedure, reference points on the seat frame are tracked as the seat is moved throughout its adjustment range, mapping the fore-aft and vertical H-point adjustment range. The ends of the midheight H-point travel path are used to determine the appropriate seat position for testing with each size ATD.

3. The seat position used for testing is determined relative to the PRP using the coordinates of the center of the steering wheel and the front and rear of the midheight H-point travel path (see step 6 in the appendix). The steering wheel center is determined by measuring two points on the steering wheel with all steering wheel adjustments set to the middle of the adjustment range.

4. Seat cushion angle, which is difficult to measure with the current H-point manikin, is no longer used in the procedure. Removing this factor simplifies the procedure without a substantial penalty in accuracy. The equations were developed using an assumed value of 14.5 degrees for the seat cushion angle, a typical value for driver seats. The transmission-type factor present in the original model has been set to the value used for automatic transmission vehicles.

ATD seat positions calculated using the revised procedures are generally within 1 mm of those calculated using the methods of Manary et al., and are consistent to within 0.1 mm of those calculated directly using the UMTRI Seating Accommodation Model equations.

The torso recline angle is set in the same manner as before, so that the sideview angle of a line from the H-point to the head CG is 12 degrees aft of vertical. Adjusting the torso to place the head CG a specified distance aft of H-point may be the best way to set and verify the 12-degree target. The current requirements that the head be level and the pelvis angle lie within a specified corridor are maintained.

## DISCUSSION

The revisions to the previous version of the procedure were undertaken with the objective of developing a procedure that can be consistently applied in an objective manner without knowledge of the vehicle manufacturer's design intent. Just as a driver gets in the vehicle and selects a seat position and seatback angle without any reference to the design seat positions and back angles, the ATDs can be positioned in relation to the vehicle interior components (and restraints) in an manner representative of human occupants.

The procedures documented in this paper have been used at IIHS in a range of vehicles and demonstrated to be functional. The procedure requires somewhat effort than current methods, and some time is required to become familiar with the new procedures. With current FMVSS procedures, an H-point drop is currently conducted prior to installing the ATD. This practice would be continued, with the additional step of measuring the vertical coordinate of the H-point manikin heel. Some calculations are required with the new procedures, but these can readily be coded in a spreadsheet for ease of use. While the procedures could be applied using only tape measures and levels, coordinate measurement equipment greatly facilitates the process. Most laboratories conducting crash and sled testing already use such equipment to ensure precise ATD positioning.

Although the discussion in this paper has focussed on positioning for frontal impact tests, the same justifications hold for other crash modes. In fact, occupant positioning may be even more critical in side impact tests, for which the arrangement of the vehicle structure and padding in the vicinity of the occupant can strongly affect the likelihood of injury. This paper is also focussed primarily on driver positioning. UMTRI has gathered a small amount of data on passenger postures in a range of vehicles. Comparisons between the postures the same people chose as drivers and passengers showed that passengers, on average, sit rearward of the their positions as drivers. Because the available data are not yet sufficient to create a usefully predictive model of passenger seat position, the best available recommendation for passenger testing is to place the passenger seat at the same fore-aft and vertical positions used for the driver.

Since publication of the original UMTRI ATD positioning model, several justifications for the current ATD positioning procedures have been raised. The results presented by Manary et al. indicate that, on average, about 10 percent of men who have a stature of 1753 mm will sit at or forward of the midtrack position. Therefore, the midtrack position might be considered to be fairly reasonable for a midsize male ATD. This argument misses the more important conclusion of the study, which is that midtrack position is a poor predictor of midsize male seat position. The standard deviation of the difference between average midsize male seat position and midtrack position across 26 vehicles was 19 mm. In some vehicles, the midsize male seat position was near the center of the seat track, while in other vehicles it was at the rear of the track.

Testing the midsize male ATD at the center of the seat track produces results that do not consistently evaluate the restraint system performance across vehicles. Pre-crash positioning has been shown to have important effects on ATD responses and the likelihood of driver injury, particularly when an airbag is part of the restraint system (7-14). If the ATD is positioned 45 mm forward of the average midsize male seating position in one vehicle, but only 10 mm forward in another vehicle, the restraint systems will not been evaluated in a manner consistent with the expected experience of the driver population. One could argue that testing the midsize male ATD at midtrack represents a more strenuous test of the restraint system than testing at a more realistic position, which would typically be more rearward. However, the results would still be inconsistent across vehicles with respect to the expected experience of the driver population.

The full-forward seat position for the small female ATD has been justified on the basis that it represents a "worst-case" scenario. For a driver, the full-forward seat position provides the maximum opportunity for airbag loading into the head and chest, and hence a test in that position probably represents a worst-case scenario for airbag loading into a normally positioned occupant. But it is not necessarily the overall worst case with respect to occupant injury likelihood, even restricting consideration to frontal impact modes. For example, an unbelted occupant sitting further rearward might develop greater speed with respect to the airbag and steering column during the impact, resulting in higher chest and head accelerations. In a real-world near-frontal crash, an unbelted occupant sitting further rearward might also be more likely to deflect off the airbag and impact the vehicle structure. In the field, these risks may be greater than the risks from airbag loading, and hence the full-forward position may not be worst-case. Most importantly, whether or not the front of the seat track is truly a worst-case scenario for occupant protection, testing at that position will be inconsistently related to the distribution of occupant experiences and risks across vehicles. Depending on the location of the seat track within the vehicle, the full-forward seat position might be used by zero to five percent of vehicle drivers.

Further, virtually all unbelted occupants can find themselves in close proximity to the airbag as a result of sub-deployment deceleration. If the objective of the small female ATD test is to assess risk due to airbag loading, a test with the ATD against the steering wheel, rather than one specified by seat position, is more appropriate. To be consistent across vehicles, a test intended to assess restraint system performance for small occupants should place the ATD at a position selected with reference to the distribution of driver positions in the vehicle.

As an alternative to the stature-based positioning calculations described here, the UMTRI seat position models can also be used to identify seat positions that correspond to particular percentiles of the driver seat position distribution. For example, the 5th percentile of the female seat position distribution is forward of the average seat position for women who are 5th percentile by stature. These findings could be used to position the small female and large male ATDs at positions selected relative to the seat position distributions. The small female ATD could be placed at the 2.5th percentile of the seat position distribution and the large male ATD could be placed at the 97.5th percentile position. These are more extreme seat positions than the average positions for people the size of the ATDs, yet there are substantial percentages of people the size of the ATDs who would sit both forward and rearward of these positions. Note that this approach would result in more consistent positioning across vehicles than the current procedures, because the positions would be set with respect to the expected distribution of driver-selected seat positions, rather than with respect to the seat track layout.

The preamble to the recently finalized revision to FMVSS 208 addressed the recommendation from the NTSB to adopt an accelerator-pedal-referenced procedure for positioning ATDs. NHTSA decided against linking the ATD position to the accelerator pedal rather than to the seat track because of the necessity for "objective" requirements. NHTSA believed that "linking the position to distance from the pedal could introduce too many ambiguities into the seating procedure for it to remain sufficiently objective." The procedure presented in this paper should provide the needed objectivity. The pedal reference point, to which the ATD position is referenced, is well defined by the procedures described in the appendix. Contingencies for any type of accelerator pedal can be readily defined. The measurement of the steering wheel location is as objectively defined as the current methods for locating adjustable steering wheels in crash testing. The H-point measurement used in the current procedures is carried over unchanged in the new procedures, and hence does not decrease the objectivity of the ATD positioning. An objective positioning procedure will yield the same ATD positions regardless of who performs the testing. While further studies will be necessary to quantify interoperator variability, the new procedure is expected to add little or no additional variability to the seating procedure.

The central motivation for the procedure described in this paper is to provide the means to assess restraint system performance in a manner that is consistently related, across vehicles, to the expected experience of the vehicle occupants involved in crashes. Currently, differences across vehicles in seat track layout yield systematic bias and large inconsistencies in ATD positioning with respect to the actual occupant positions in the vehicle. ATD injury assessment values obtained under the current procedures may be less useful for comparison among vehicles than those obtained with more representative ATD positions.

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**APPENDIX**

**UMTRI ATD POSITIONING PROCEDURE**
**Revised September 2000**

1. Perform H-Point Measurement

The H-point measurement should be performed in the same way as in the current procedures, i.e., with the seat at the middle of the fore-aft seat adjustment range, using 50th-percentile-male thigh and leg segment lengths. If the seat is vertically adjustable, it should be placed in its full-down position. The seat back angle should be set to 23 degrees (as measured by the manikin torso angle) or to the manufacturer's specified seat back angle. The vertical coordinate of the lowest point on the heel of the manikin's right shoe should be recorded to define the heel rest surface height. The H-point location should be recorded, along with two reference points on the seat frame that will move with the seat cushion. Ideally, these points will be bolt heads or some other well-defined reference points, one near the front and one near the rear of the seat frame. It is useful to move the seat on all its adjustment axes while selecting these points to ensure that they are fixed with respect to the seat cushion.

2. Define H-Point Travel Range

The objective of this step is to define the full range of available seat position adjustment. After removing the H-point manikin from the seat, use the seat controls to put the seat in the full-down, full-rear position. Record the locations of the two seat-frame reference points. Use the adjuster mechanism to move the seat to the full-forward position, while leaving the seat in its full-down position. Record the reference point locations. Leaving the seat in the full-forward position, use the height adjuster to raise the seat to its highest position. Record the reference point locations. With the seat in its highest position, move the seat full rear and record the reference point locations. Using the measured relationship between the reference points and the H-point, compute translated/rotated H-point locations for each of the extreme seat positions. These four locations define the H-point travel range (see Figure 1).

*Seats without vertical adjustment* — Determine the H-point location at the front and rear of the fore-aft adjustment range. If the seat cushion angle changes as the seat track position is adjusted (e.g., because of a curved track or a mechanical linkage), ensure that the H-point calculation with respect to the two reference points includes this movement.

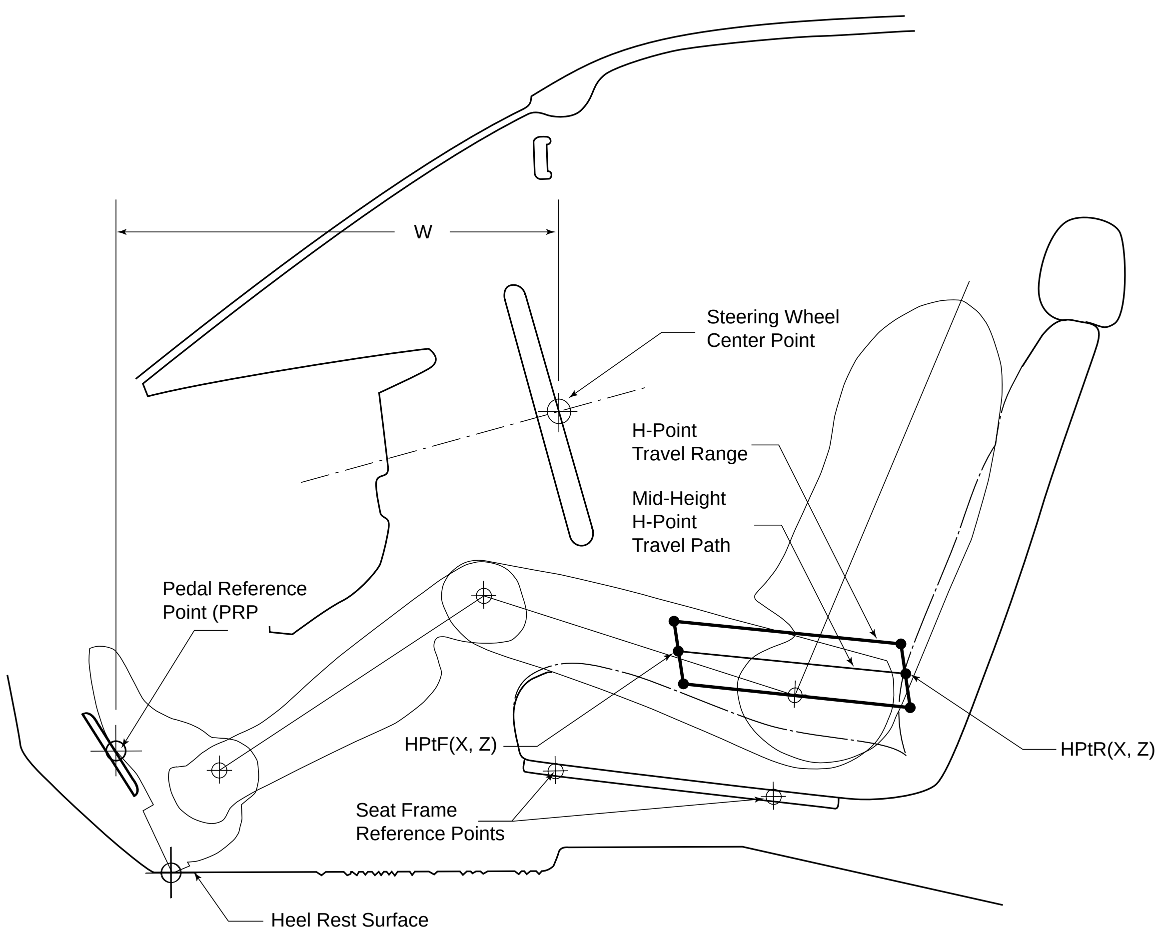


Figure 1. H-point travel range and other locations and dimensions used in this procedure.

3. Establish Pedal Reference Point

The pedal reference point (PRP) is a point on the accelerator pedal from which fore-aft dimensions are measured in this procedure. The seat H-point location to be used for testing is measured with respect to the PRP. The PRP is defined in sideview using the midline contour of the undepressed accelerator pedal, as illustrated in Figure 2. The PRP lies on the surface of the pedal at the lateral midline and is 200 mm from the heel rest surface. The heel rest surface is the horizontal plane passing through the H-point manikin heel point. The PRP is located as follows:

3.1 Place masking tape or some other markable material on the accelerator pedal surface. If necessary, block the accelerator pedal so that it remains in its rest position during measurement. Mark a line defining the lateral center of the pedal. If the pedal is inclined in the plane perpendicular to the surface (for example, if the top of the pedal is inboard of the bottom of the pedal), make the line pass through the lateral center of the pedal at each vertical level. The PRP is used for fore-aft reference dimensions only, so the lateral position of the pedal centerline is important only as if it affects the fore-aft position of the PRP.

3.2 Use a coordinate measurement machine (CMM) to record points on this line. If the pedal is flat, only two points defining the top and bottom of the line are required. A stream of points should be taken for a curved pedal.

3.3 If a CAD system is available, transfer the data to CAD, referencing the points to the vertical position of heel rest surface. If a CAD system is not available, the point may be located physically using a straight-edge and a coordinate measurement machine.

3.4 For a flat accelerator pedal: Construct a line in side view (XZ plane) tangent to the accelerator pedal, i.e., at the angle of the undepressed accelerator pedal. The PRP is the point on this line that is 200 mm from the heel rest surface. For an extremely low or high pedal, the PRP may not lie on the pedal surface. Note that the tangent line will generally not pass through the measured manikin heel location.

For a curved accelerator pedal: Construct a line in side view (XZ plane) tangent to the accelerator pedal such that the distance from the contact point on the pedal to the heel rest surface along the tangent line is 200 mm. The contact point when this condition is met is the PRP. Note that the tangent line will generally not pass through the measured manikin heel location. For curved pedals, the PRP is always on the pedal surface.

3.5 Mark the PRP location on the pedal and record its location with the CMM.

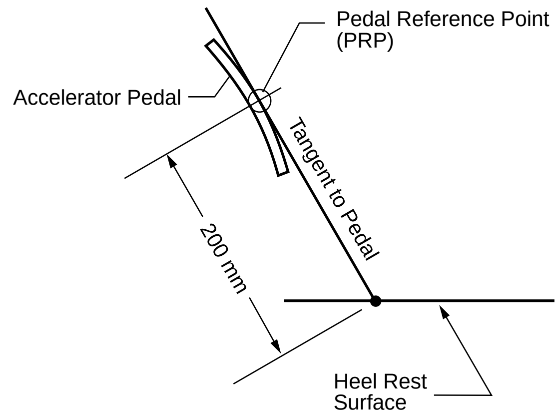


Figure 2. Pedal reference point definition.

4. Establish the Steering Wheel Center Point

The location of the steering wheel center point is determined with the steering wheel at the center of any adjustment ranges, such as tilt or telescope. The steering wheel center point is defined to be the intersection between the pivot axis of the steering wheel and the plane tangent to the driver side of the steering wheel rim. To locate this point, measure the locations of points on the driver side of the steering wheel rim at the top and bottom of the wheel (see Figure 3) with the wheel in the neutral position. Turn the wheel 180 degrees and record the positions again. Use the spatial average of these four measurements to define the steering wheel center point.

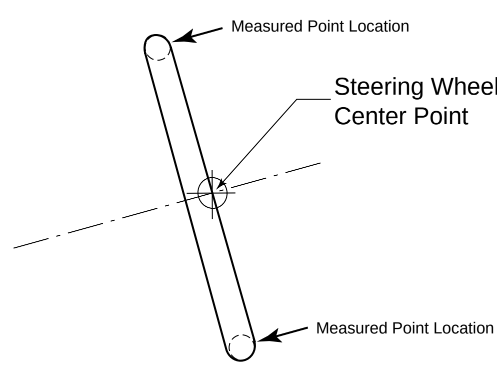


Figure 3. Steering wheel center point calculated from measured point locations on wheel rim.

5. Calculate the Seat Position (H-Point Location with Respect to the Vehicle) for ATD Testing

These calculations are performed in side view, using X and Z coordinates only.

5.1 Calculate the midpoints of the front and rear of the H-point travel range, as shown in Figure 1. For a seat without height adjustment, use the most-forward and most-rearward H-point locations in the H-point adjustment range. These two points define the H-point (seat) track angle.

5.2 Calculate the seat track rise $r = \Delta Z/\Delta X$:

$$r = \frac{HPtFZ - HPtRZ}{HPtRX - HPtFX}$$

The seat track rise *r* should be zero or positive, indicating the increase in H-point height for each unit of forward movement of the seat along the mid-height H-point travel path.

6. Calculate Seat H-Point Location for Testing

The fore-aft H-point location (X coordinate) aft of the PRP to be used for ATD testing is given by

$$HPtX(mm\ aft\ of\ PRP) = -15.0 + 0.433\,S + 0.41W$$

$$-\ \frac{0.24}{1 - 0.3943r}\ (HPtRZ + r\,(HPtRX - 1054))$$

where

| | |
|---|---|
| *S* | is the ATD reference stature (see below), |
| *W* | is the fore-aft distance between the PRP and the steering wheel center point, |
| *HPtRZ* | is the vertical coordinate of the rear of the mid-height H-point travel path with respect to the heel rest surface, and |
| *HPtRX* | is the horizontal coordinate of the rear of the mid-height H-point travel path with respect to PRP. |

*S* is set to:
1511 mm for the small adult female ATD,
1753 mm for the midsize adult male, and
1870 mm for the large adult male.

For seats with vertical adjustment, the vertical position of the seat H-point location used for testing is given by

$$\text{HPtZ (mm)} = \text{HPtRZ} + \text{r (HPtRX} - \text{HPtX)}$$

i.e., the location along the mid-height H-point travel path that lies HPtX mm rearward of PRP.

7. Position the Seat for Testing

Using the measured offset between the seat H-point and the seat frame reference points, place the seat in the appropriate position, using the CMM to verify the seat position.

8. Position the ATD in the Seat

Recline the seatback fully and place the ATD in the seat. Follow established procedures for placement of the legs and feet. Bring the seatback up to support the ATD torso in approximately the correct attitude. Adjust the ATD as necessary to position the ATD H-point in the correct position with respect to the seat H-point location determined in step 5.

9. Adjust the ATD Torso Orientation

Adjust the seatback recliner so that (1) the pelvis angle is within the specification, and (2) the angle of a side-view line from the ATD H-point to the ATD head CG lies 12 degrees rearward of vertical. If necessary, the nodding block may be adjusted to level the head.

10. Complete Positioning and Test Preparation

Complete positioning as specified in current practice, including arms and hands.