



SURFACE VEHICLE STANDARD

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H-Point Machine (HPM-II) Specifications and Procedure for H-Point Determination - Auditing Vehicle Seats

RATIONALE

This revision consolidates the HPM-II/ASPECT manikin auditing and calibration into one document. Minor updates have been included to optional measurement procedures to reflect current practices. Procedures for auditing the seat have been reaffirmed per the SAE Five-Year Review policy.

For HPM-I audit and calibration procedure, please refer to SAE J826.

INTRODUCTION

The tools and procedures for H-point determination given in this standard are based on the SAE HPM-II H-point machine.

H-point devices are used during vehicle design and development to establish interior reference points and dimensions for occupant packaging, and to validate the location of these key reference points and dimensions on physical properties during audits.

H-point devices are also used for the design and validation of seats. However, in these instances, the reference points and dimensions are defined relative to the seat structure and/or surface, rather than the vehicle's interior. The procedures for positioning the H-point devices in seats do not require the use of the shoe tool or leg segments.

For convenience and simplicity, many terms associated with H-point devices use human body parts in their name. However, they should not be construed as measures that indicate occupant accommodation, human capabilities, or comfort. H-point devices do not represent the size or posture of any category of occupant.

H-points measured with the HPM-II are not equivalent with measures taken with the SAE HPM-I manikin. All measurements made with the HPM-II should clearly indicate that the HPM-II was the source.

Key differences from SAE J826: Compared to the H-point machine described in SAE J826, the changes made have resulted in improved repeatability, greater ease of use, and additional features and measurement capabilities. Several of the changes are discussed below.

1. Separate components: For the HPM-II, the legs (upper and lower), shoe, cushion pan, and back pan are all separate pieces. This greatly improves the ease of installation.
2. "Legless" manikin: The new tools allow the H-point location to be defined without having to attach the legs. This is a major advantage of the HPM-II. The new procedure is based on installing the HPM-II without legs. Use of legs is optional.

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3. Shoe tool: Several improvements were made to the shoe tool and how it is positioned in the vehicle, including:
 - a. Replacing the pedal reference point (PRP) with a new ball of foot reference point (BOFRP), and
 - b. Defining a new standard procedure for positioning the shoe on the pedal.
4. Cushion angle: The cushion angle can now be measured independently of thigh angle, and at the same time the other measurements are made. Previously, cushion angle was measured from the thigh line, and required a separate installation of the HPM.
5. Lumbar support: The articulation of the back pan assembly allows the HPM-II to be better seated in contoured seats. It also provides a new measurement called lumbar support prominence (LSP). This measurement provides an indication of the amount the seat back is contoured to provide support for the lumbar spine. The contour of the new back pan assembly is most similar to the original H-point machine when the HPM-II is in a neutral posture (LSP equals zero).

H-points measured with the HPM-II cannot be used for any measurements that require the SAE HPM-I manikin. All measurements made with the HPM-II should clearly indicate that the HPM-II was the source.

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1. SCOPE

This SAE Standard provides the specifications and procedures for using the H-point machine (HPM¹) to audit vehicle seating positions. The HPM is a physical tool used to establish key reference points and measurements in a vehicle (see Figure 1 and Appendix A). The H-point design tool (HPD) is a simplified CAD² version of the HPM, which can be used in conjunction with the HPM to take the optional measurements specified in this document, or used independently during product design (see Appendix D).

These H-point devices provide a method for reliable layout and measurement of occupant seating compartments and/or seats. This document specifies the procedures for installing the H-point machine (HPM) and using the HPM to audit (verify) key reference points and measurements in a vehicle.

The devices are intended for application at designated seating positions. They are not to be construed as tools that measure or indicate occupant capabilities or comfort. They are not intended for use in defining or assessing temporary seating, such as folding jump seats.

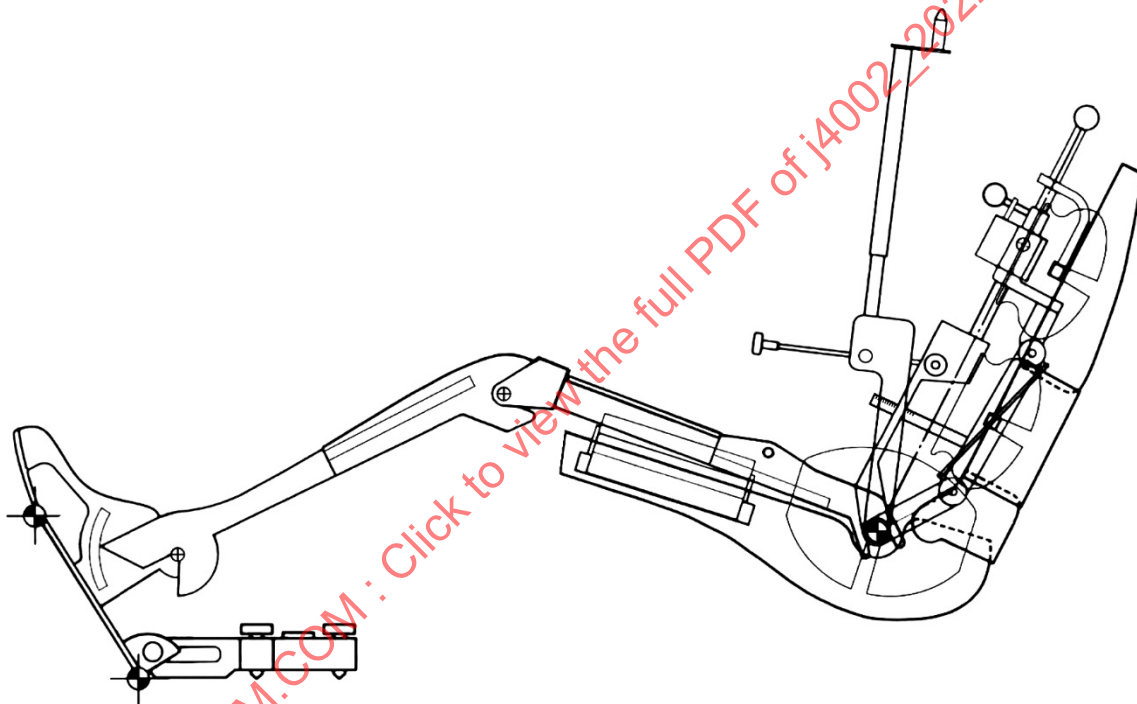


Figure 1 - Side view of HPM, including optional components

¹ All references to H-point machine or HPM in this standard refer to the SAE H-point machine (HPM-II), unless otherwise noted.

² CAD is an acronym for computer-aided design. In a general sense, it has come to encompass any software system/approach to automotive design and development, and is often used to refer to CAE (computer-assisted engineering) and CAM (computer-assisted manufacturing) software systems as well.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J182 Motor Vehicle Fiducial Marks and Three-Dimensional Reference System

SAE J1100 Motor Vehicle Dimensions

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J826 Devices for Use in Defining and Measuring Vehicle Seating Accommodation

SAE J3103 Benchmark H-Point Procedure

Bush, T., Gregg, S., and Hubbard, R., "Measuring and Modeling Support Forces of People to Assist in the Development of the ASPECT Manikin Weighting," SAE Technical Paper 1999-01-0961, 1999, <https://doi.org/10.4271/1999-01-0961>.

Flannagan, C., "Reproducibility and Repeatability of the SAE J4002 and J826 H-point Machines," SAE Technical Paper 2005-01-1010, 2005, <https://doi.org/10.4271/2005-01-1010>.

Manary, M., Flannagan, C., Reed, M., and Schneider, L., "Human Subject Testing in Support of ASPECT," SAE Technical Paper 1999-01-0960, 1999, <https://doi.org/10.4271/1999-01-0960>.

Reed, M., Roe, R., and Schneider, L., "Design and Development of the ASPECT Manikin," SAE Technical Paper 1999-01-0963, 1999, <https://doi.org/10.4271/1999-01-0963>.

Reed, M., Roe, R., Manary, M., Flannagan, C. et al., "New Concepts in Vehicle Interior Design Using ASPECT," SAE Technical Paper 1999-01-0967, 1999, <https://doi.org/10.4271/1999-01-0967>.

Roe, R., Reed, M., and Schneider, L., "ASPECT Manikin Applications and Measurements for Design, Audit, and Benchmarking," SAE Technical Paper 1999-01-0965, 1999, <https://doi.org/10.4271/1999-01-0965>.

Schneider, L., Reed, M., Roe, R., Manary, M. et al., "ASPECT: The Next-Generation H-Point Machine and Related Vehicle and Seat Design and Measurement Tools," SAE Technical Paper 1999-01-0962, 1999, <https://doi.org/10.4271/1999-01-0962>.

3. DEFINITIONS

For the purposes of this standard, the following definitions apply. Several of the reference points established with an H-point device are required for the subsequent positioning of other design devices, such as head contours, eyellipses, and reach curves. The most important reference points established by an H-point device are the H-point, the H-point travel path, the SgRP (seating reference point), the AHP (accelerator heel point), and the BOFRP (ball of foot reference point). These reference points are illustrated in Figure A8. Terms used in this document but not defined herein are defined in SAE J1100.

3.1 H-POINT

Point at the pivot center of the back pan and cushion pan assemblies, located on the lateral centerline of the H-point device (HPM or HPD).

NOTE: H-points are often referred to as hip points or hip pivot points. They simulate but do not precisely represent the location of the human hip joint.

3.2 H-POINT TRAVEL PATH

All possible locations of the H-point provided by the full range of seat adjustments (horizontal, vertical, or tilt) for a given designated seating position.

3.3 SgRP (SEATING REFERENCE POINT), R-POINT, DESIGN H-POINT

Manufacturer's intended location for a design H-point, which is specifically designated as R-point or SgRP, and which:

- a. Is the fundamental reference point used to establish occupant accommodation tools and dimensions;
- b. Simulates the position of the pivot center of the human torso and thigh;
- c. Has coordinates established with respect to the designed vehicle structure;
- d. Establishes the rearmost normal design driving or riding H-point of each designated seating position, which accounts for all modes of adjustment: horizontal, vertical, and tilt that are available for the seat, but does not include seat travel used for purposes other than normal driving and riding.

3.4 AHP (ACCELERATOR HEEL POINT)

Point representing the heel of shoe (HOS) location on the depressed floor covering, when the bottom of shoe is in contact with the undepressed accelerator pedal and the ankle angle is at 87 degrees. The lateral location (Y coordinate) is aligned with the BOFRP unless shoe interference with side support structure causes an offset of the AHP from the BOFRP. See 5.1.3.1.

3.5 BOFRP (SHOE REFERENCE POINT)

Point representing the ball of foot (BOF) location on the shoe plane when the HPM shoe is set to a specified shoe plane angle, the bottom of shoe is in contact with the undepressed accelerator pedal, the ball of foot is aligned with the lateral centerline of the undepressed accelerator pedal in rear view and the heel of shoe is at the depressed floor covering.

The BOFRP and AHP are at the same Y coordinate unless there is lateral shoe interference.

3.6 FRP (FLOOR REFERENCE POINT, REAR PASSENGER)

Point at the intersection of the heel of shoe and the depressed floor covering, with the bottom of shoe resting on the depressed floor covering. It is determined within 127 mm to either side of centerline of occupant, with the shoe and/or lower leg segment moved forward to rest against the seat in front (contacting the underseat structure, lower portion of the seat back trim, etc.).

3.7 LSP (LUMBAR SUPPORT PROMINENCE)

Measure of the back pan shape imposed on the HPM by the contour of the lower seatback (see Table A4).

3.8 SPA (SHOE PLANE ANGLE)

Angle from horizontal to the bottom of the HPM shoe when the shoe is in contact with the undepressed accelerator pedal and the shoe heel is at the AHP.

NOTE: SPA is provided by the vehicle manufacturer or calculated from the manufacturer's published seat height H30-1 (see 5.1.3).

4. MEASUREMENT PROCEDURE FOR THE THREE-DIMENSIONAL H-POINT MACHINE

A complete description of the three-dimensional H-point machine is given in Appendix A. Specifications and tolerances are given in Appendix B. A field checking procedure for the HPM is given in Appendix C.

The HPM includes divot points that can be used by a coordinate measuring machine (CMM) and in CAD to fully define the location of the machine in the vehicle space (see A.3.3). Calibrated planar surfaces on the HPM facilitate field measurement of machine angles using an inclinometer. A scale readout indicates the LSP (lumbar support prominence) value. An ankle angle scale is provided to aid HPM installation in long-coupled passenger seating.

4.1 Summary of Installation Procedure

Table 1 - Summary of installation procedure

Driver Position	2nd and 3rd Row Passenger Positions
Prepare the physical property. If possible, calibrate the CMM equipment to vehicle grid coordinates.	
Position seat to design intent location and attitude.	Position the test seat and (if the HPM legs will be installed) the seat in front of the test seat to design intent location and attitude.
Install shoe fixture and shoe tool, if measuring leg and shoe dimensions. Record shoe-based measurements. See 5.1.	Install shoe tool, if measuring leg and shoe dimensions. Record shoe-based measurements. See 6.1.
Install and load the cushion pan and back pan. If measuring head room, install head room fixture before loading the pans. See 7.1. Determine H-point, torso angle, cushion angle, and LSP. See 4.8.	
Attach thigh and lower leg segments, if measuring leg-based dimensions. See 5.1.	Attach thigh and lower leg segments, if measuring leg-based dimensions. See 6.1.
Determine optional measurements. See 5.2 and 7.1.	Determine optional measurements. See 6.2 and 7.1.

4.1.1 Measured versus Design Values

When verifying or auditing a particular designated vehicle seating position, measurements taken with the three-dimensional HPM are normally compared to the design values indicated by the vehicle manufacturer. If any measured value is sufficiently close to the manufacturer's design value, the vehicle/seat is considered to meet the manufacturer's design intent for that measurement. The vehicle manufacturer or a regulatory agency may provide specifications for the term "sufficiently close." Two HPM measurements of particular interest are H-point (SgRP) and torso angle.

4.2 Prepare Vehicle and Seat

4.2.1 Vehicle

Dimensions are measured relative to the vehicle three-dimensional reference system by setting up the vehicle relative to the fiducial marks (refer to SAE J182) as specified by the manufacturer. The vehicle (or seating buck) shall be leveled prior to any HPM installation or measurement. Once the vehicle is leveled, care should be taken to not lean on it, rock it, or in some other way knock it off level.

If the accelerator pedal is needed for the measurements, the accelerator pedal shall be held in an undepressed position by some means. For example, use blocks or clamp the accelerator cable to prevent the pedal from moving. If the pedal rotates about a pivot, independent of throttle movement, do not restrict that motion. If the accelerator pedal has fore/aft adjustment, the pedal shall be positioned as specified by the manufacturer. If no specification is provided, the pedal shall be adjusted to its most forward position in the vehicle.

4.2.2 Seat

The vehicle shall be preconditioned at the manufacturer's discretion, at a temperature of 19 to 26 °C to ensure that the seat material reaches room temperature. Room relative humidity should be within a range of 50% $\pm$ 5%. If this relative humidity is not met, record both relative humidity and room temperature.

The following considerations will help ensure that stable, reliable measurements are made across seat types. If the seat to be checked has never been sat upon, a 70 to 80 kg person or device shall sit on the seat to flex the cushion and back. Prior to the installation of the HPM, seats should remain unloaded for 30 minutes at the manufacturer's request. This is to allow the seat and seat materials (e.g., foam) to recover from compression.

Muslin cloth should be placed over the seat prior to installing the HPM. The muslin cloth may be a single piece fitting across both seat cushion and seat back, or two pieces, one for the cushion and one for the seat back. This ensures a constant friction surface across seat fabrics. See B.11.

When using the H-point machine (HPM), interactions can occur between adjacent seating positions (i.e., having an HPM installed at the center occupant position can change the results obtained for the outboard occupant position). Therefore, only one machine should be installed in a particular row of seats during each test.

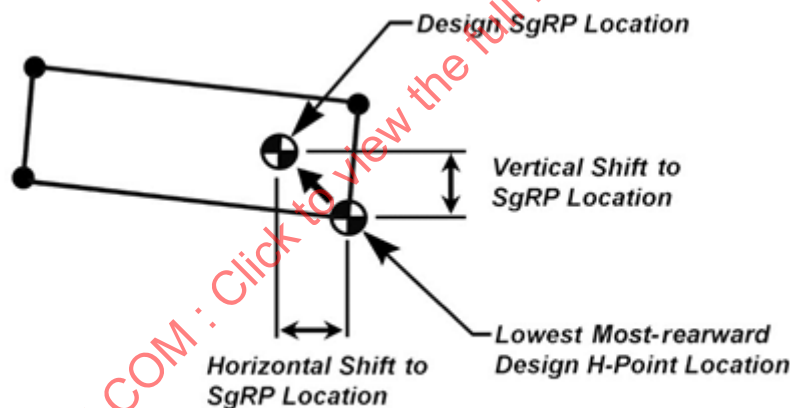


Figure 2 - Locating SgRP from the seat travel path

4.3 Adjust Seat to Design Intent

4.3.1 Move Seat to Design Intent Position

All adjustable features of the seat shall be set to manufacturer's design intent attitude or position before installing the HPM.

For seats with an independent vertical adjustment or suspension, the vertical position shall be rigidly fixed in a position specified by the manufacturer.

Normally the design intent position specified by the vehicle manufacturer is the seating reference point (SgRP). Figure 2 illustrates a typical way to set the seat to design intent position from the rearmost lowest position.

4.3.1.1 Torso Angle and Cushion Angle

Seat torso and cushion angle adjustment procedures for auditing differ depending on whether or not variance in seat build is of interest.

4.3.1.2 Standard Audit: Include Seat and Vehicle Build Variability

The seat shall be adjusted to the design intent torso angle and cushion angle before installing the HPM. The vehicle manufacturer (or seat supplier) shall provide information regarding the location and attitude of the discernable seat structure (e.g., the seat frame), other hard points (e.g., seat controls, pivot points, head restraint rods, etc.), or the amount of adjustment required to attain the desired seat attitude.³

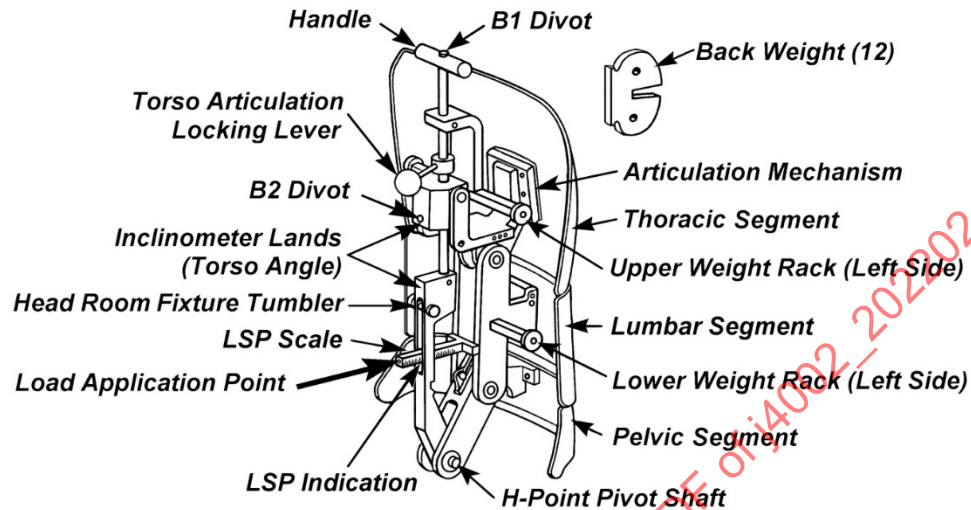


Figure 3 - Back pan

4.3.2 Seat in Front of Test Seat

If leg positions, leg room, foot room, and knee clearance are to be measured, the seat in front of the test seat should be positioned to its SgRP and design intent torso angle.

4.4 Install HPM Cushion and Back Pan Assembly

4.4.1 Install the Cushion Pan

Place the cushion pan (Figure 4) on the seat with the back of the pan resting lightly against the seat back. Visually center the cushion pan laterally in the seat.

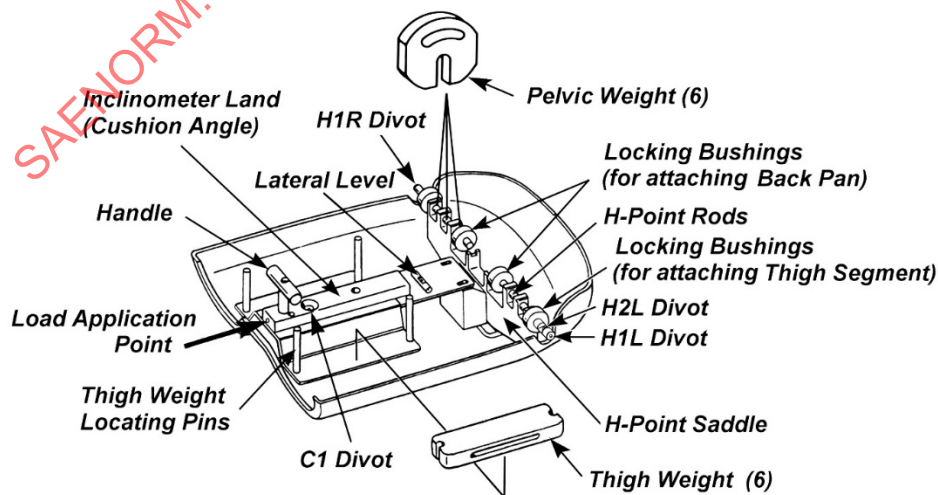


Figure 4 - Cushion pan

³ The seat can also be audited independent of the vehicle.

4.4.2 Install the Back Pan

To protect the shells of the cushion and back pans, the back pan should be locked in a slouched position before installing it. Articulate the back pan into a slouched position ($LSP < 0$) and lock.

Place the H-point pivot shaft, located at the base of the back pan, on the H-point saddle of the cushion pan (see Figures 3 and 4). The upper portions of the back pan should not contact the seat back. Secure by sliding the brass locking bushings inwards over the H-point shaft.

Unlock the torso articulation. Put one hand firmly on the cushion pan T-handle to maintain the position of the cushion pan. Put the other hand on the back pan T-handle and gently rotate the back pan assembly against the seat back to allow the back pan assembly to conform to the seat back contour. Ensure that the top and bottom corners at each side of the lumbar segment remain outside the thoracic and pelvic segments. Also ensure that the muslin cloth is not caught between the back segments (Figure 5).

NOTE 1: The cushion and back pan can be connected and installed as a single unit if preferred. Follow the same steps as above, centering the cushion pan lightly against the seat back with the back pan rotated forward and locked in the slouched position.

NOTE 2: If measuring head room, install the head room fixture now (see 7.1).

4.4.3 Level the HPM

Referring to the bubble level on the cushion pan, dither and adjust the HPM so it is level laterally on the seat. Make sure the HPM is in firm contact with the seat back.

4.5 Load the HPM

Installing weights on the HPM is referred to as “loading.” The HPM shall be loaded with the torso articulation mechanism unlocked. Weights shall be installed from the H-point outward and from the H-point upward to prevent the HPM from toppling out of the seat. Prior to each round of weights being loaded, an 89 N force shall be applied twice by “punching” the appropriate load application site with the spring-loaded probe. The operator shall immediately release any applied force once the punch probe reaches its spring loading. This procedure ensures the HPM remains fully nested into the seat during the loading.

The HPM shall be checked for level during the loading process. The sequence of actions for loading the HPM, summarized in Table 2, shall be followed.

Table 2 - Loading the HPM

Round	Apply 89 N	Load 2 Weights	THEN Load 2 Weights	Check for:
1	Punch twice (cushion)	2 Pelvic - innermost positions	2 Thigh	Level
2	Punch twice (cushion)	2 Pelvic - next innermost positions	2 Thigh	Level
3	Punch twice (cushion)	2 Beveled pelvic - outermost positions	2 Thigh	Level
4	Punch twice (back)	2 Lower rack - innermost positions	2 Upper rack - innermost positions	Level
5	Punch twice (back)	2 Lower rack - next innermost position	2 Upper rack - next innermost positions	Level
6	Punch twice (back)	2 Lower rack - outermost positions	2 Upper rack - outermost positions	Level
7	Lock torso articulation			

4.5.1 Load the Cushion Pan

There are two types of weights for loading the cushion pan; pelvic weights, which are positioned in slots along the H-point axis, and thigh weights that are held in place by the pins in the thigh area.

Punch the HPM twice at the cushion pan load application point (Figure 5). Install two pelvic weights in the innermost pelvic weight slots (one to either side of the H-point). Install two thigh weights (one to either side). Check for level.

Repeat these steps (punch twice, load two pelvic weights, load two thigh weights, and level) two more times to complete the loading of the cushion pan.

4.5.2 Load the Back Pan

There are two areas for loading weights on the back pan assembly, the lower and upper racks. However, the same type of weight is used in both areas.

NOTE: When auditing the vehicle but not the seat build, adjust the seat cushion or seat back recliner if necessary during the loading to obtain a final cushion and torso angle that equals design intent (see 4.4.2.2). The adjustments should be made after checking the cushion or back pan for level in each round shown in Table 2.

Punch the HPM twice at the back pan load application point (Figure 5). Install two weights on the lower racks—one on either side of centerline. Push the weights toward the centerline as far as possible. Install two weights on the upper racks, one on either side of centerline, and push towards the centerline. Check for level.

Repeat these steps (punch twice, load two weights on the lower rack, load two weights on the upper rack, and level) two more times.

After the back pan is fully loaded and level, lock the torso articulation mechanism.

The completed HPM installation is shown in Figure 5.

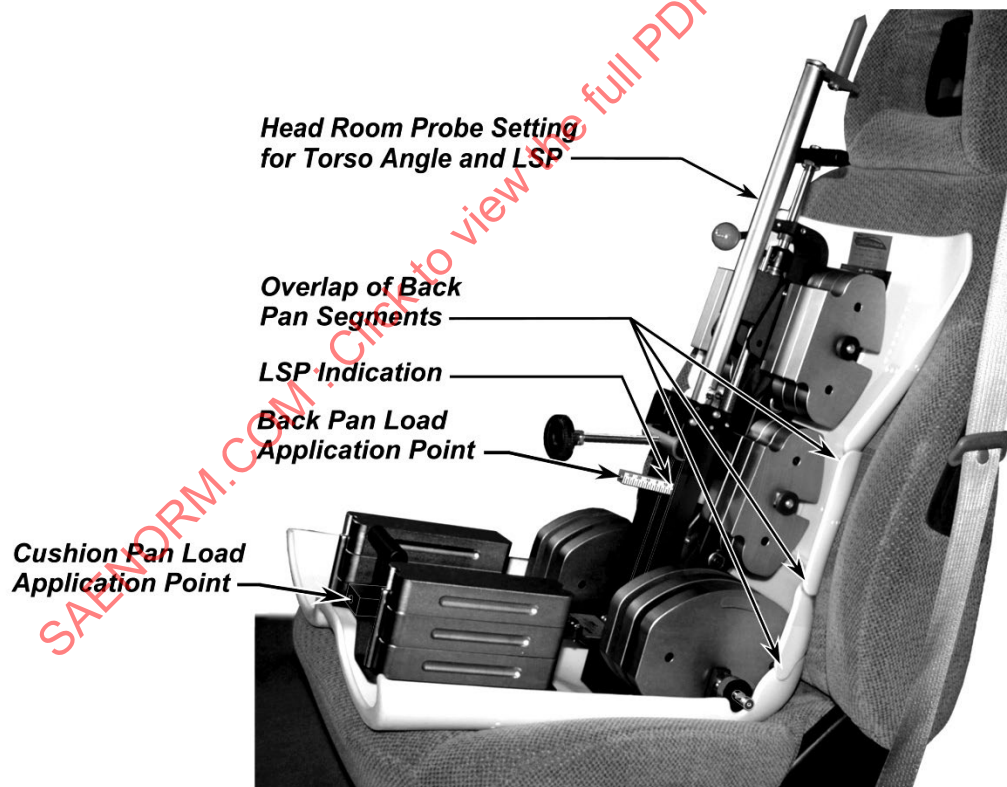


Figure 5 - H-point machine installed in a seat

4.6 Soak Time

After installation, the HPM can continue to “settle” into a seat, depending on the type of seat being used. Therefore, the installer should wait 5 minutes after completing the HPM installation before recording data.

4.7 Record Measurements—Digitize HPM Points

The HPM allows the H-point location, torso angle, lumbar support prominence, and cushion angle to be defined without attaching the legs.

4.7.1 H-Point

The H-point is located at the lateral centerline of the HPM. Therefore, this point cannot be directly digitized. Rather, divot points H1L and H1R are provided for digitizing at either end of the H-point rods (see Figure 4). If either H1L or H1R is not readily accessible by the CMM, use divots H2L and H2R. Both H1L and H1R or H2L and H2R should be digitized. The H-point is midway between these two points. Divot points B1, B2, and C1 may be used to establish the HPM center plane in CAD to check the Y coordinate of the H-point.

The digitized H-point, which represents the measured SgRP, shall be compared to the design SgRP to assess the accuracy of the seat build.

4.7.2 Torso Angle and Cushion Angle

Record the following measurements using an inclinometer and the appropriate land: torso angle, using the head room fixture land or back assembly land; cushion angle, using the cushion pan inclinometer land. As an alternative, the torso angle can be calculated from divot points H1L, H1R, and B1, and the cushion angle from divot points H1L, H1R, and C1. H2L and H2R can be used in lieu of the H1 divots.

4.7.3 Lumbar Support Prominence

The HPM provides a scale on the back pan assembly for a direct read-out of the lumbar support prominence (Figure 5).

4.7.4 Summary of Driver Measurements

Table 3 shows the standard and optional measurements for the driver seat position.

Table 3 • Driver measurements

SAE J1100 Code ^a	Dimension
L31, W20, H70	SgRP X, Y, and Z coordinates
A40	Torso angle
A27	Cushion angle
L81	Lumbar support prominence (LSP)
Optional Measurements (Leg and Shoe Attached)	
L8, W8, H8	Accelerator heel point X, Y, and Z coordinates
L1, W1, H1	BOFRP X, Y, and Z coordinates
PW86	BOFRP to AHP lateral offset
A47	Shoe plane angle (SPA)
A57	Thigh angle
A42	Hip angle
A44	Knee angle
A46	Ankle angle
H30	Seat height
H61	Effective head room
L33	Maximum leg room
L34	Effective leg room

^a A suffix (-2, -3, etc.) that denotes the seat row must be added to each dimension code.

5. OPTIONAL MEASUREMENTS FOR DRIVER SEAT

5.1 Leg and Shoe Installations

If the user plans to measure shoe and leg dimensions, the shoe fixture and shoe tool should be installed before the HPM cushion and back pans are installed (see Table 1). The shoe tool is used to establish the ball of foot reference point (BOFRP) and the accelerator heel point (AHP) for the driver.

5.1.1 Mark Accelerator Pedal Centerline

Before installing the shoe tool in the driver compartment, place masking tape down the longitudinal center of the accelerator pedal, and draw a line along the accelerator centerline.

5.1.2 Install the Shoe Fixture

The shoe fixture is used to hold the shoe level and in place on the pedal (Figure A4). Position the forward edge of the shoe fixture approximately 100 to 150 mm rearward of the accelerator pedal such that the fork that will hold the shoe tool is in line with the accelerator centerline. The fixture shall be square to the grid and level. Adjust the screws on the shoe fixture until it is level.

5.1.3 Install the Shoe Tool

Place the shoe in the fixture, set the shoe plane angle (SPA) at the manufacturer specified angle, tighten the shoe locking screw to hold the shoe in place and slide the shoe forward. The shoe shall be positioned with the heel on the depressed floor covering, the bottom of shoe contacting the pedal face and the BOF aligned with the pedal centerline. For flat, free-pivoting pedal pads, the bottom of the shoe should be flush with the face of the pedal. When there is a single point of contact, that point is the pedal contact point (PCP). Where there is continuous contact—e.g., with a suspended, flat pivoting pedal—there is not a specific PCP. See Figure 8.

If the manufacturer does not specify a SPA, calculate the SPA from Equation 1.

$$\text{SPA} = 2.522(10^{-7})(H30^3 - 3.961(10^{-4})(H30^2) + 4.644(10^{-2})(H30) + 73.374 \text{ degrees from horizontal} \quad (\text{Eq. 1})$$

Check to make sure the shoe tool is square to the grid. Adjust the fixture and shoe if necessary.

The SPA is measured directly by placing the inclinometer on the rearward-facing surface of the shoe. Alternatively, the shoe plane angle can be calculated from the z-coordinates of divot points S3 and S2.

$$\text{SPA} = \text{Shoe Plane Angle} = \arcsin [(S3_z - S2_z)/94] \quad (\text{Eq. 2})$$

5.1.3.1 Interference

Occasionally, some aspect of the vehicle's structure—such as the tunnel, rocker, center console, etc.—prevents the positioning of the shoe tool and fixture as described in 5.1.3. If the interference prevents the shoe tool from being properly positioned at the accelerator centerline, the shoe and fixture shall be shifted laterally until the interference is cleared. The amount of the lateral offset, PW86, should be recorded. The BOFRP is defined at the centerline of the accelerator pedal, even though the shoe BOF will not be at the centerline. The AHP is defined at the location of the heel of shoe after the shoe tool is moved to clear the interference (see Figure 6).

In some cases the shoe tool may fit properly, but the shoe fixture cannot. The tool and fixture will still need to be moved to clear the interference, but the AHP location is defined as if the shoe were aligned at the pedal centerline. In other words, the AHP coordinates are defined as if the shoe had remained positioned on the pedal centerline with no interference. This translation is most easily done in CAD.

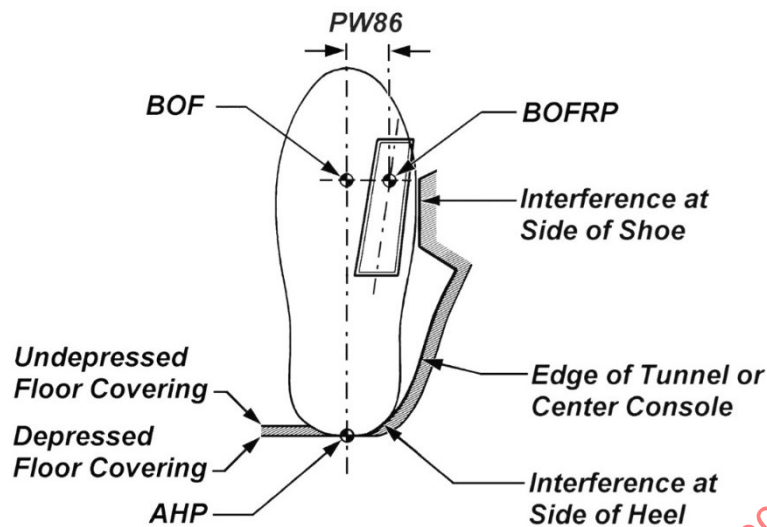


Figure 6 - AHP to BOFRP lateral offset

5.1.4 Install Leg Segments

When taking the shoe and leg measurements in 5.2 and 6.2 for the purpose of reporting these dimensions to outside organizations, set the leg segments at the SgRP leg lengths; i.e. pin the thigh length to 456 mm and the lower leg to 459 mm. Manufacturers may use non-SgRP leg lengths for other purposes.

Install the thigh segment by placing the forks on the H-point rods. Slide the locking bushings inward and rotate until the pins lock into place (Figures 4 and 7). Install the lower leg at the ankle pivot without moving the shoe. Join the thigh and lower leg segments, raising the thigh segment if necessary. Use the bushing on the knee pivot rod to secure the lower leg in place.

The completed HPM installation, including optional components, is shown in Figure 7 for the driver seating position. Optional components include the HPM legs, shoe tool and shoe fixture, and the head room probe.



Figure 7 - Perspective view of HPM, including optional components

5.2 Record Measurements

The shoe measurements (5.2.1, 5.2.2, 5.2.3, and 5.2.4) should be recorded immediately after installation of the shoe tool (see Figure 8).

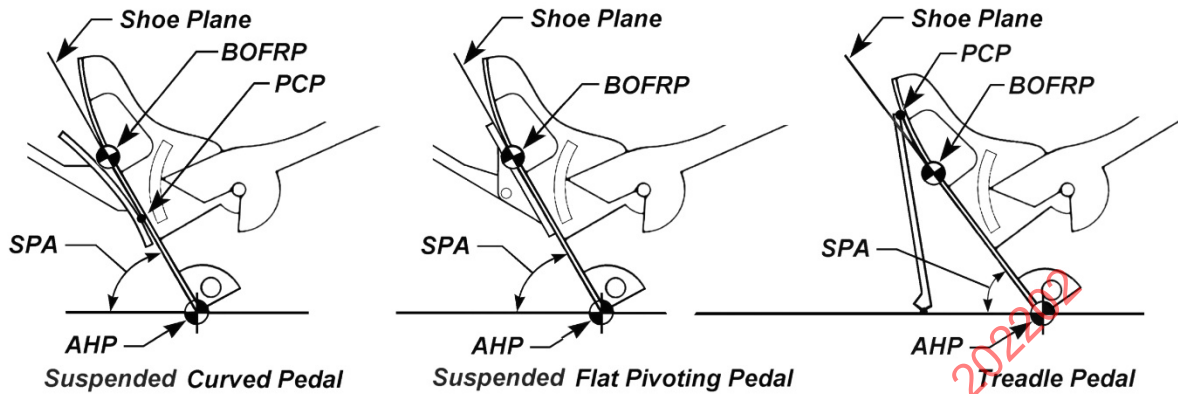


Figure 8 - Shoe reference points related to accelerator pedal

5.2.1 Shoe Plane Angle

Record the SPA determined in 5.1.3.

5.2.2 Ball of Foot Reference Point

The BOF point can be digitized directly, or it can be calculated using the following equations.

$$\text{BOF}_x = \text{BOFRP}_x = S3_x - 25 * \cos(\text{SPA}) - 5 * \sin(\text{SPA}) \quad (\text{Eq. 3})$$

$$\text{BOF}_z = \text{BOFRP}_z = S3_z + 25 * \sin(\text{SPA}) - 5 * \cos(\text{SPA}) \quad (\text{Eq. 4})$$

The location of the pedal contact point (PCP) relative to BOFRP can be measured by a scale on the shoe tool (Figure 9). The PCP may be digitized, if desired.

5.2.3 Accelerator Heel Point

The AHP cannot be directly digitized. It is calculated using the shoe divot points (S1, S2, and S3), and the equations below.

$$\text{AHP}_x = S3_x + 175 * \cos(\text{SPA}) - 5 * \sin(\text{SPA}) \quad (\text{Eq. 5})$$

$$\text{AHP}_z = S3_z - 175 * \sin(\text{SPA}) - 5 * \cos(\text{SPA}) \quad (\text{Eq. 6})$$

AHP_y and BOF_y are defined at the shoe centerline, and can also be determined from the divot point locations. The S1, S2, and S3 divot points are offset 10 mm to either side of the shoe centerline. The direction of the 10 mm correction to an S_y location will depend on which side of the shoe was digitized (see Figure 9).

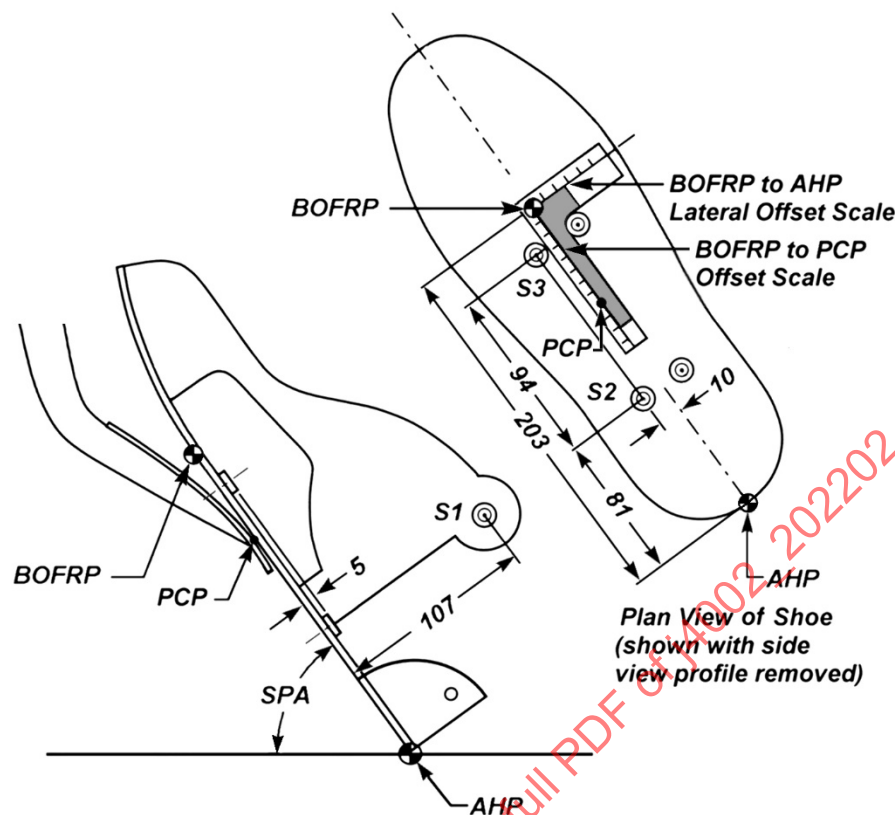


Figure 9 - Shoe divot points

5.2.4 AHP to BOFRP Lateral Offset

The AHP to BOFRP lateral offset, PW86, can be read off the AHP to BOFRP lateral offset scale (see Figure 6). This offset is used to correct the y-coordinate of the BOFRP, if necessary.

5.2.5 Knee Angle and Ankle Angle

Both can be read directly on the scales provided.

5.2.6 Thigh Angle and Hip Angle

The thigh angle is measured using an inclinometer and the inclinometer land provided on upper leg segment (Figures A3 and A8).

The hip angle can be calculated from the torso and thigh angles as follows:

$$\text{Hip Angle} = 90 \text{ degrees} - \text{thigh angle} + \text{torso angle} \quad (\text{Eq. 7})$$

6. OPTIONAL MEASUREMENTS FOR SECOND OR SUCCEEDING ROW PASSENGER SEATS

6.1 Leg and Shoe Installation

If the user plans to measure shoe and leg dimensions, the shoe tool should be installed before the HPM cushion and back pans are installed. The shoe tool is used to establish the floor reference point (FRP) and floor plane angle for passengers. The leg segments are used to measure minimum knee clearance, effective legroom, as well as hip, thigh, knee, and ankle angles. These dimensions are defined in SAE J1100.

The shoe installation differs from the procedure described for driver's seats, but the leg and thigh installations are the same. The shoe fixture is not needed for passenger seat positions.

6.1.1 Install the Shoe Tool

Place the shoe tool on the floor and slide it forward, beneath the seat in front, until it reaches an obstruction. The shoe can be placed anywhere within ± 127 mm of occupant centerline, and should be positioned such that its movement forward is optimized (see Figure 10A).

If the shoe cannot fit on the floor between the seats, measurement of knee clearance (L48), leg clearance (L58), and leg room (L51) is best done in CAD. If a physical installation of the HPM shoe and legs is desired, move the preceding seat forward along its seat adjustment path until the shoe just fits between the seats (Figure 10C). Move the shoe laterally within ± 127 mm of occupant centerline, keeping the rear of the shoe against the trim under the test seat, to find the location that requires the least amount of preceding seat movement. Record the seat movement. This movement shall be subtracted from the leg room measured in 6.2.3 (see Figures 10C and 11).

If the shoe cannot fit and the preceding seat does not have fore/aft adjustment, then measurement of knee clearance, leg clearance, and leg room must be done in CAD. Move the seat horizontally forward in CAD to determine the amount to be subtracted from leg room.

NOTE: The H-point design (HPD) shoe shown in Appendix D, along with the lower leg and thigh, can be installed in CAD, if the preceding seat back, trim under the test seat, and the floor were digitized.

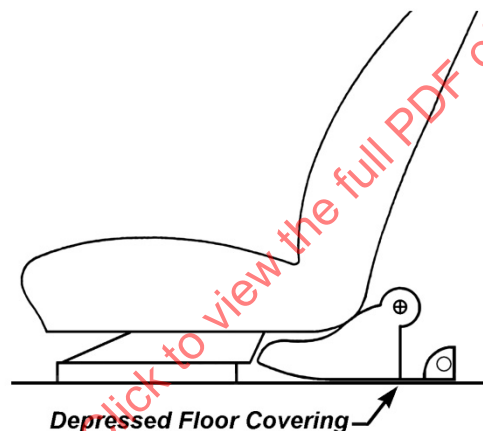


Figure 10A - Shoe is first positioned as far forward as possible

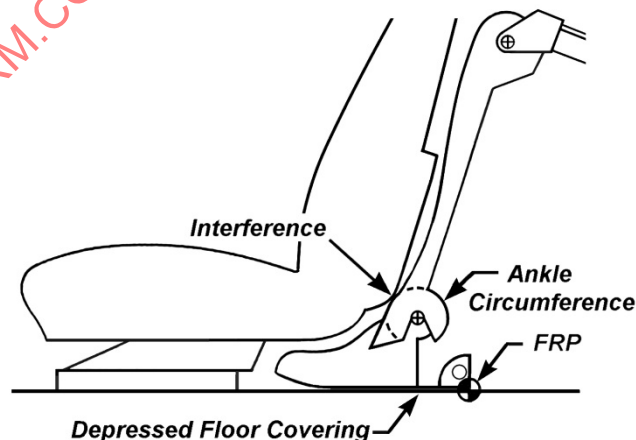


Figure 10B - Shoe may need to be moved rearward to eliminate ankle interference with lower seat back trim

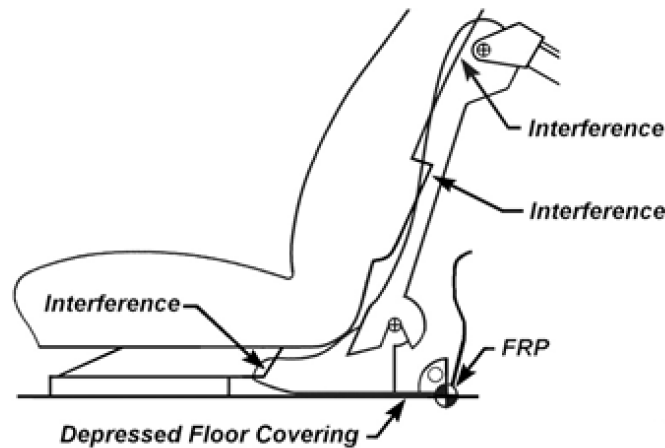


Figure 10C - Short-coupled seating: the seat interferes with the knee, leg, or shoe, requiring the seat be moved forward to allow installation of the leg and shoe

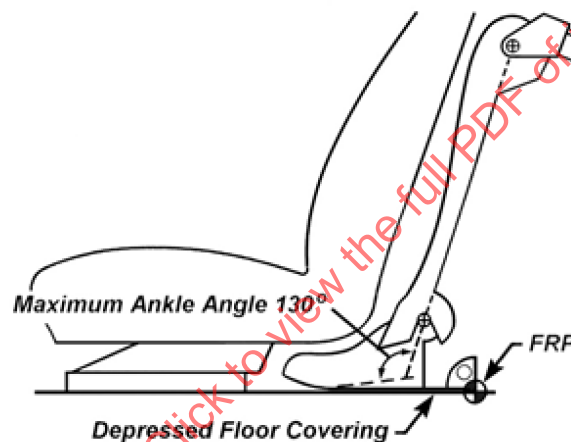


Figure 10D - Long-coupled seating: the shoe must be moved rearward so the longer leg reaches the shoe with an ankle angle no more than 130 degrees

Figure 10 - Shoe and leg installation for rear passenger seats

6.1.2 Install Leg Segments

Install the thigh segment and lower leg segment as for the driver (see 5.1.4). In some vehicles, the thigh and lower leg/ankle segments cannot be attached without first repositioning the shoe tool or moving the preceding seat forward (see Figure 10, 6.1.2.1, and 6.1.2.2).

6.1.2.1 Reposition the Shoe Tool (If Necessary)

There are two conditions under which the shoe tool will need to be moved rearward:

- Interference between the preceding seat back or seat trim and the ankle circumference of the lower leg segment or shoe tool (Figure 10B).
- The lower leg segment does not reach the shoe tool, or, if it does reach, the ankle angle exceeds 130 degrees (Figure 10D). This condition is called long-coupled seating.

In either of these events, the shoe tool shall be repositioned before FRP or floor plane angle can be defined.

6.1.2.1.1 Interference

Temporarily attach only the lower leg to the shoe to determine if there is interference in the area of the ankle pivot circumference on the lower leg (Figure 10B). If there is interference at the ankle circumference, move the shoe rearward to just clear the interference. Interference above the ankle pivot circumference is not considered for positioning the shoe but will be considered when determining knee or leg interferences with short-coupled seating. Use this shoe position to define the FRP, floor plane angle, and all other dimensions.

If there is interference above the ankle circumference, proceed to 6.1.2.2. Otherwise, attach the thigh and lower leg segments now (see 5.1.4).

6.1.2.1.2 Long-Coupled Seating

Prior to moving the shoe rearward, record the ankle pivot point (S1 divot) so that leg room can be correctly calculated. Use this shoe position to establish the floor reference point, floor plane angle, and all other dimensions except leg room. Move the shoe rearward until the cushion pan-thigh-lower leg assembly can be attached to the shoe tool at the ankle pivot point, with an ankle angle of 130 degrees.

6.1.2.2 Short-Coupled Seating

In vehicles with short-coupled seating, the knee or the lower leg segment interferes with the seat back of the seat directly ahead (Figure 11B). In this case mark the SgRP location of the preceding seat. Move the preceding seat forward to allow the lower leg and thigh to be installed. Do not move the shoe.

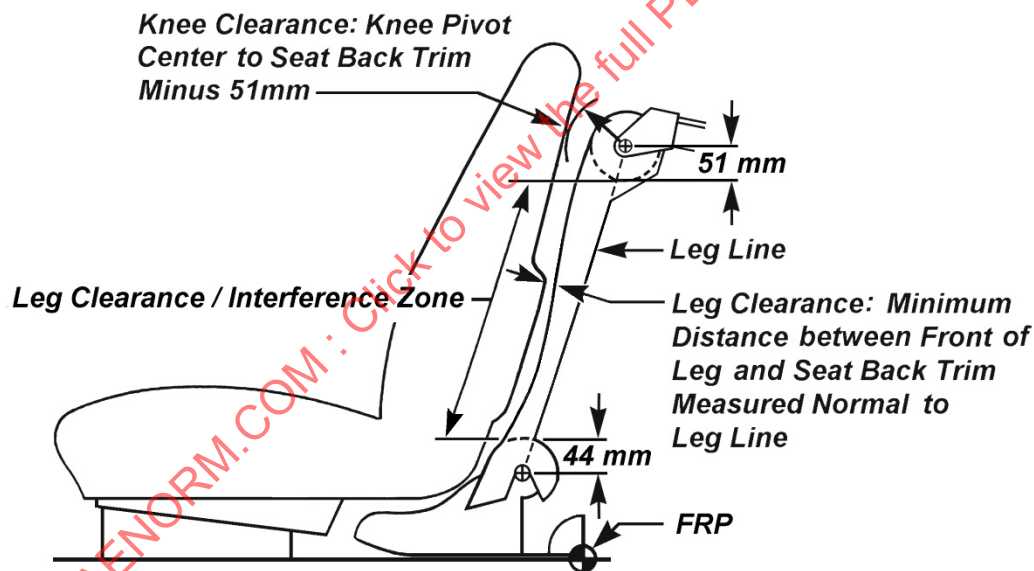


Figure 11A - Leg and knee clearances

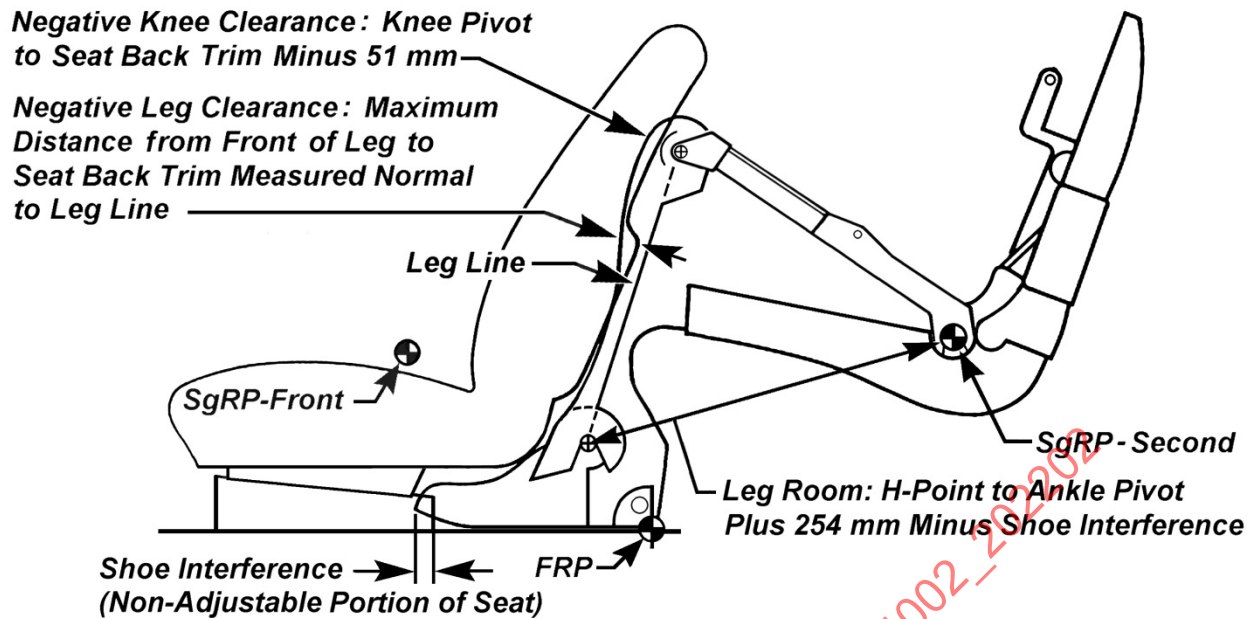


Figure 11B - Shoe, leg, and knee interferences

Figure 11 - Knee clearance, leg clearance, and leg room for short-coupled seating

6.2 Record Measurements for Rear Passengers

The completed HPM installation is shown in Figure 12 for the rear outboard seating position.

For knee angle, thigh angle, hip angle, and ankle angle, proceed in the same way as for the driver seat (see 5.2.5 and 5.2.6).



Figure 12 - H-point machine installed in rear outboard seat

Table 4 lists the passenger measurements that can be taken.

Table 4 - Rear passenger measurements

SAE J1100 Code ^a	Dimension
L31, W20, H70	SgRP X, Y, and Z coordinates
A40	Torso angle
A27	Cushion angle
L81	Lumbar support prominence (LSP)
Optional Measurements (leg and shoe attached)	
L98, W98, H98	Floor reference point X, Y, and Z coordinates
A48	Floor plane angle
A57	Thigh angle
A42	Hip angle
A44	Knee angle
A46	Ankle angle
H30	Seat height
H61	Effective head room
L48	Knee clearance
L58	Leg clearance
L51	Effective leg room

^a A suffix (-2, -3, etc.) that denotes the seat row must be added to each dimension code.

6.2.1 Floor Reference Point (FRP)

The shoe divot points can be digitized, and the FRP calculated by using the AHP equations in 5.2.3. Other divot points can be digitized if desired.

6.2.2 Floor Plane Angle

The floor plane angle is measured directly by placing the inclinometer on the rearward-facing surface of the shoe “sole.” Alternatively the floor plane angle can be calculated from the coordinates of the divot points S3_z and S2_z by using the following equation.

$$\text{FPA} = \text{Floor Plane Angle} = \arcsin [(S3_z - S2_z)/94] \quad (\text{Eq. 7})$$

6.2.3 Knee Clearance and Leg Room

Knee clearance is the minimum distance between the knee pivot point (K1 divot) and the preceding seat back, minus 51 mm (Figure 11). The measurement is taken within 127 mm to either side of the occupant centerline. This measurement is best done in CAD from a scan of the preceding seat back in the vicinity of the K1 divot point and lower leg of the HPM. Knee clearance will be a negative value if the knee interferes with the preceding seat back. Refer to SAE J1100 for a decision tree explaining long- and short-couple CAD procedures.

If there is interference below the knee and above the ankle circumference, use the leg clearance dimension (L58) in SAE J1100 to determine the amount of interference. For short-coupled seating, measurement of knee and leg interferences shall be done in CAD.

Leg room is the distance in side view along a line from the ankle pivot center (S1 divot point) to the SgRP, plus 254 mm, measured within 127 mm to either side of the occupant centerline, with the heel of shoe at the FRP. The knee clearance and leg room measurements are shown in Figure 11 for a short-coupled vehicle.

7. ADDITIONAL OPTIONAL MEASUREMENTS

7.1 Effective Head Room

If the user plans to measure head room (H61), the head room fixture should be installed immediately after the HPM cushion and back pans are installed, before weights are added (see Table 1).

7.1.1 Install the Head Room Fixture

Slide the forks at the end of the head room fixture into the grooves on the brass locking bushings of the cushion pan. With the adjuster screw fully out, snap the end of the screw into the rotating tumbler on the back pan (see Figures 4 and 13). Ensure the fixture is fully against the stop on the back pan.

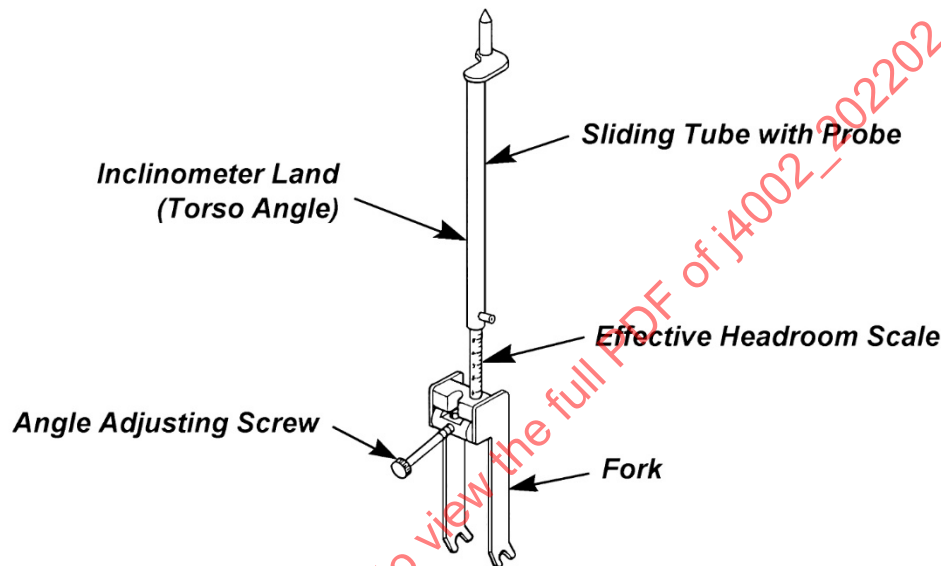


Figure 13 - Head room fixture

8. REMOVE THE HPM

To aid in removing the HPM, seats may be moved, unless a subsequent HPM installation will be made in the succeeding row.

Remove lower leg segment, if installed.

Remove thigh segment if installed.

Weights are removed from the HPM in the reverse order that they were installed. Unload the HPM following the removal order of Table 5.

Table 5 - Unloading the HPM

Round	Remove 2 Weights from:	Then Remove 2 Weights from:
1	Outermost upper rack	Outermost lower rack
2	Next outermost upper rack	Next outermost lower rack
3	Innermost upper rack	Innermost lower rack
4	Thigh	Outermost pelvic
5	Thigh	Next outermost pelvic
6	Thigh	Innermost pelvic

Remove head room fixture, if installed.

Remove cushion and back pans: Unlock the torso articulation mechanism, position the back pan in a slouched posture, and re-lock the mechanism. Slide the brass locking bushings outward and remove the back pan. Remove the cushion pan. Alternatively the cushion and back pan can be removed as a single unit.

Remove shoe tool and shoe fixture, if installed.

9. NOTES

9.1 Revision Indicator

A change bar (|) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY THE HUMAN ACCOMMODATION AND DESIGN DEVICES STANDARDS COMMITTEE

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APPENDIX A - (NORMATIVE)
DESCRIPTION OF THE THREE-DIMENSIONAL H-POINT MACHINE (HPM)

A.1 AVAILABILITY

The HPM is available from SAE International, 400 Commonwealth Drive, Warrendale, PA, 15096-0001.

A.2 MAJOR COMPONENTS

This section provides descriptions of the parts and some basic dimensions of the HPM. Complete dimensional information can be found in Appendix B.

For the HPM, the leg segments (thigh and lower leg), shoe tool, cushion pan and back pan assembly are all separate pieces (see Figure A1).

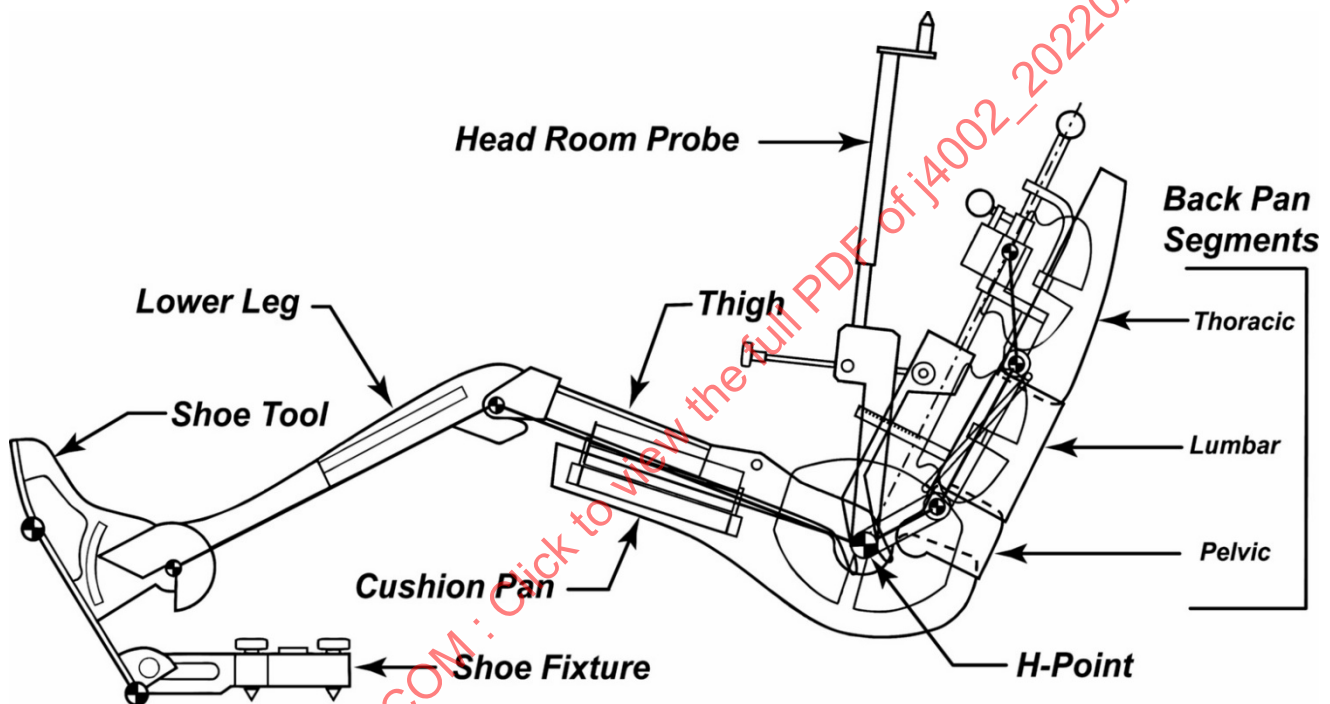


Figure A1 - Major new HPM components

A.2.1 Back Pan Assembly

The back pan assembly consists of the back pan with its thoracic, lumbar, and pelvic segments. It contains the following parts (see Figure 3):

- Handle
- Torso articulation locking lever
- H-point pivot shaft (sits on H-point saddle)
- Load application point (receptacle for spring-loaded probe)
- Torso angle inclinometer land
- Upper weight rack
- Lower weight rack

A.2.2 Cushion Pan

The cushion pan assembly contains (see Figure 4):

- Cushion pan
- Handle
- H-point saddle with pelvic weight locations
- H-point rods
- Locking bushings for attaching back pan
- Locking bushings for attaching thigh segment
- Load application point for spring probe
- Lateral level
- Thigh weight platform and locating pins

A.2.3 Lower Leg Segment

The lower leg segment includes (see Figure A2):

- Knee pivot slot
- Leg length scale
- Leg length locking pin
- Leg length locking screws
- Knee angle scale
- Lower leg angle inclinometer land

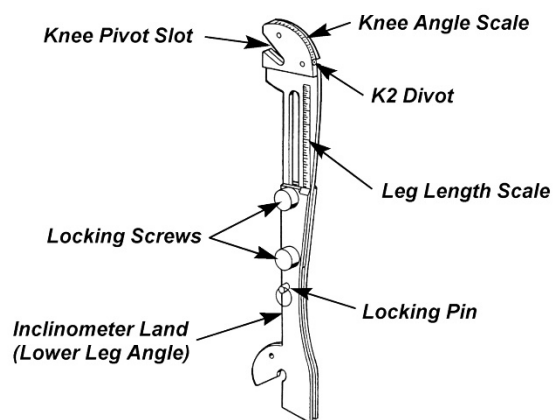


Figure A2 - Lower leg segment

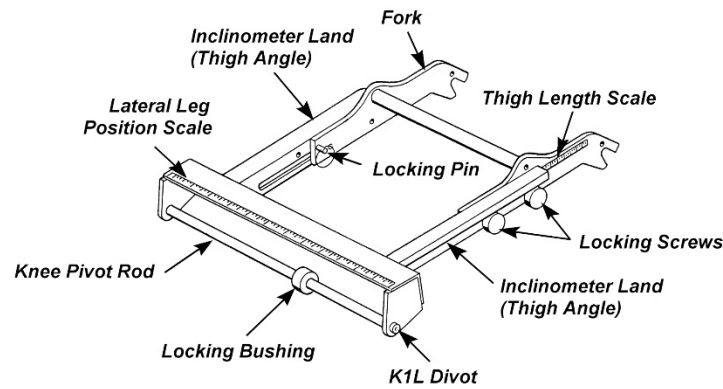


Figure A3 - Thigh segment

A.2.4 Thigh Segment

The thigh segment consists of (see Figure A3):

- Locking bushing (for attaching lower leg)
- Knee pivot rod
- Thigh length scales
- Thigh length locking pins
- Thigh length locking screws
- Fork (for attaching to H-point rod)
- Lateral leg position scale
- Thigh angle inclinometer land

A.2.4.1 Length of Thigh and Lower Leg Segments

The length of the leg segments can be adjusted. However, for measurements related to the SgRP (or R-point), the SgRP leg length values shall be used (see Table A1).

Table A1 - Leg segment lengths

Leg Segment	SgRP	Mid-Size Male
Thigh (knee pivot to H-point)	456 mm	432 mm
Lower Leg (knee pivot to ankle pivot)	459 mm	417.5 mm

A.2.5 Shoe Tool and Shoe Fixture

The ball of foot (BOF), heel of shoe (HOS), and bottom of shoe are found on the shoe tool, and are key reference points or surfaces for using the H-point machine. BOF on the shoe tool is located at the zero marking (corner) of the two scales on the top surface of the shoe. Other parts of the shoe tool include (see Figure A4):

- Locking screw
- Ankle angle (typically 87 degrees for the driver)
- AHP to BOFRP lateral offset scale

- BOFRP to PCP (pedal contact point) scale
- Shoe plane angle inclinometer land

The shoe fixture is used to hold the shoe tool in place on the accelerator (see Figure A4).

- Two leveling screws
- Bubble level
- Fork for attaching the shoe tool

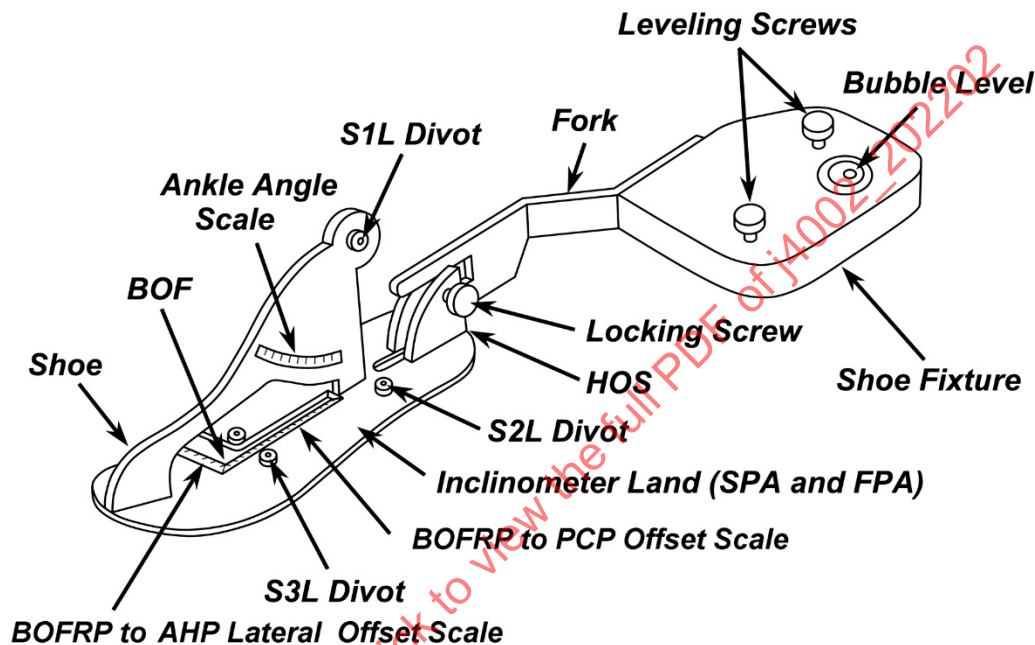


Figure A4 - Shoe tool and shoe fixture

A.2.6 Spring-Loaded Probe

The probe is used to deliver 89 N (20 pounds) of force at the appropriate load application points.

A.2.6.1 Load Application Sites

There are two sites for applying force using the spring-loaded probe; one on the cushion pan and one on the back pan (see Figures 3 and 4).

A.2.7 Inclinometer (Electronic Level)

An inclinometer is provided for determining various posture angles when using the HPM, including torso angle, thigh angle, cushion angle, and shoe plane angle. Specific sites for placing the inclinometer—referred to as lands—are provided on the appropriate components.

A.2.7.1 Inclinometer Lands

There are six locations provided for positioning the inclinometer: lower leg, thigh, head room fixture, shoe tool, back pan, and cushion pan.

A.2.8 Weights

The HPM comes with three types of weights: pelvic, thigh, and back. The total number of weights is 24: six pelvic, six thigh, and 12 back. Two of the pelvic weights have beveled edges. See Appendix B for a full specification.

A.2.9 Head Room Fixture

A separate fixture is provided for measuring effective head room. The fixture consists of (see Figure 10):

- Fork (for attaching to the HPM)
- An adjusting screw for setting the angle of the fixture
- A land for measuring the angle of the fixture
- A sliding tube with probe
- Effective head room scale

A.3 REFERENCE POINTS AND ANGLES

A.3.1 Pivot Locations

The HPM can be articulated about six pivot locations: ankle pivot, knee pivot, H-point (where cushion and back pan are joined), lumbar-pelvic pivot, thoracic-lumbar pivot, and sliding thoracic pivot (see Figure A5). In the HPM, the pivot point centers lie within the pivot mechanism.

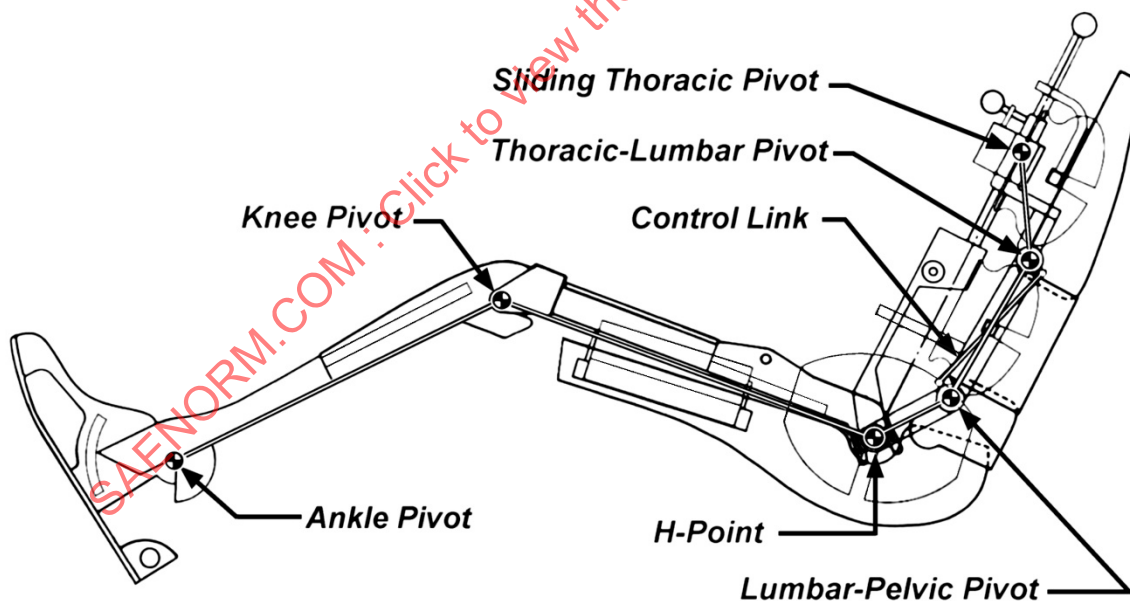


Figure A5 - Pivot points

A.3.2 Support Points

There are nine support points: five are located on the bottom surface of the cushion pan and four are on the outer surface of the back pan assembly (see Figure A6). The support points are provided to facilitate seat design. Additional information can be found in Appendix B.

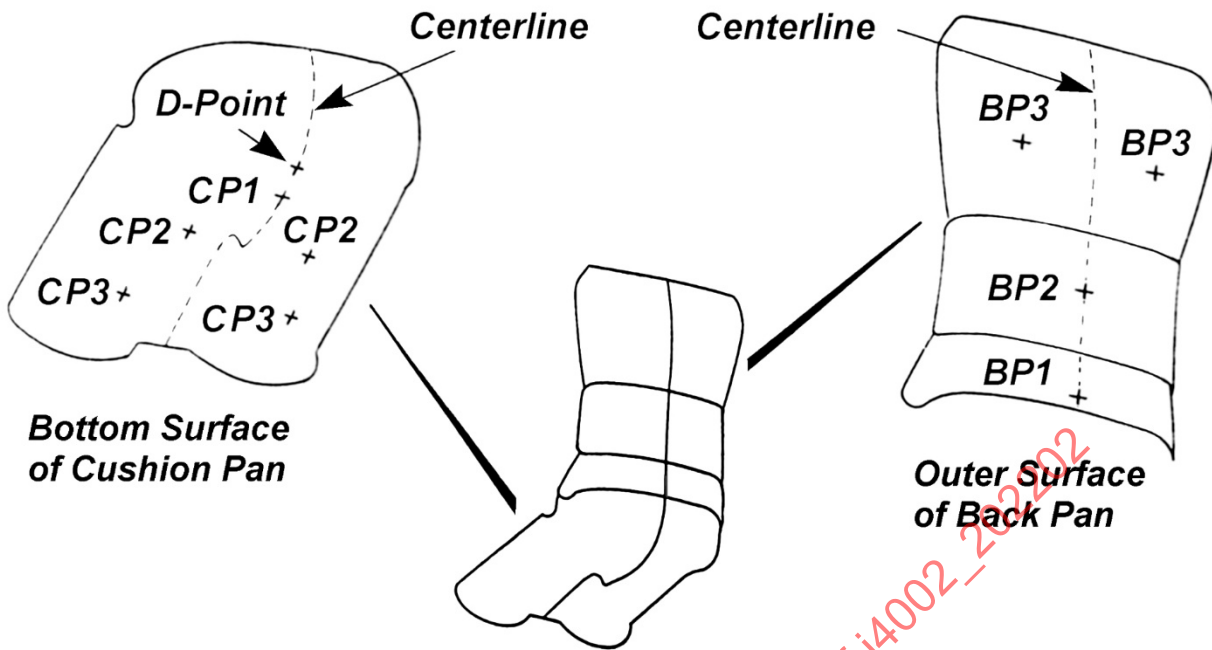


Figure A6 - Support points

A.3.3 Divot Points

Fourteen divot points are provided on the HPM for use with CMM⁴ equipment (see Figure A7). On the HPM, divot points are located in the center of the small gold colored disks on the mechanism. Specific locations of the divot points can be found in Appendix B. The primary purpose of the divot points is to allow for the calculation of key reference points.

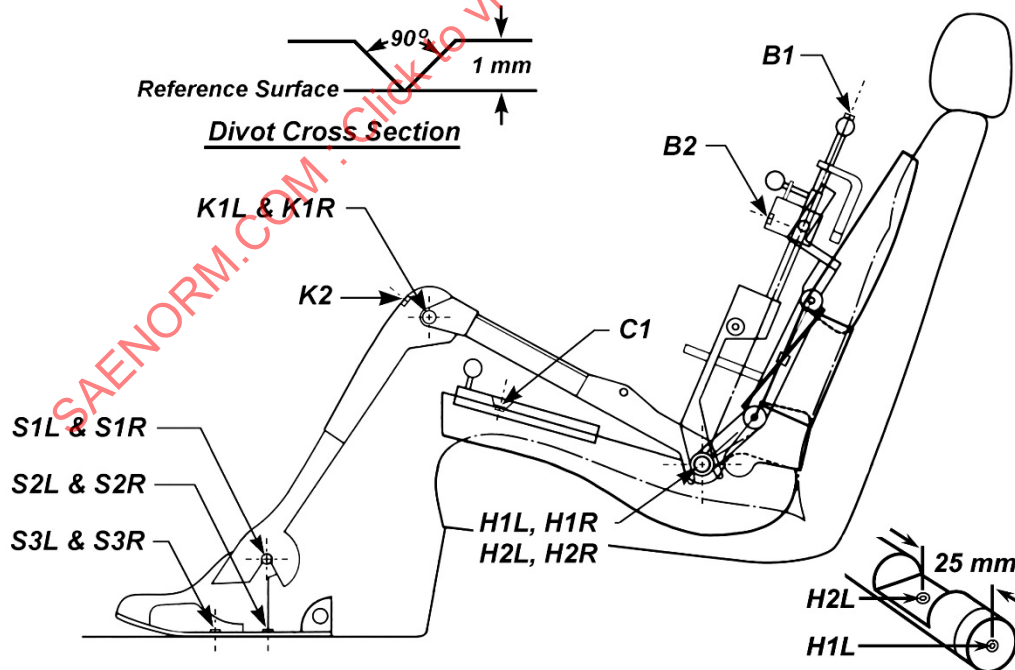


Figure A7 - Divot points on the HPM

⁴ A CMM (coordinate measuring machine) is a computer assisted three-dimensional system for the measurement and digitizing of physical properties. Typically, data from a CMM can be captured as individual points or streams of data. The 3D information provided includes the X, Y, and Z coordinates of the points. This information can then be read into the appropriate CAD environment.

For example, the coordinates of H1L and H1R (or H2L and H2R) are required to calculate the H-point location. The coordinates of S1, S2, and S3 are required to calculate the location of the accelerator heel point (or floor reference point). Divot points can also be used to calculate with additional precision anything that can be measured directly from the HPM (e.g., torso angle, cushion angle, knee angle, lumbar support prominence, etc.). See Table A2.

Table A2 - Divot point overview

Divot Type	Summary of Use
Back Pan Divot Points (B1, B2) and Cushion Pan Divot Points (C1, H1R, H1L)	The B1 point can be used with the H1 or H2 points to define the torso angle. This can then be compared to B2 for a measure of lumbar support. The C1 point can be used with the H1 or H2 points to define the cushion angle. Additionally, B1 and B2 can be used together with C1 to define the centerline of the HPM.
H-Point Divot Points (H1R & H1L or H2L & H2R)	The H1 or H2 points are used to define the H-point location. The measured H-point is located at the intersection of centerline of the HPM, the torso line and the cushion line. The H1 or H2 locations are averaged to define the X, Y, and Z coordinates of the H-point. (Alternatively, B1, B2, and C1 can be used to define the H-point y coordinate.)
Shoe Divot Points (S1R, S1L, S2R, S2L, S3R, & S3L)	Shoe divot points are used to define the AHP (accelerator heel point). They can also be used to define the BOFRP (ball of foot reference point), the shoe plane angle, and the floor plane angle.
Knee Divot Points (K1L, K1R, & K2)	Knee divot points can be used to locate the knee pivot point center. By using this in combination with the S1 and H1 or H2 points, knee angle can be determined.

A.3.4 Key Reference Points and Lines

For the HPM, the key reference points and reference lines need to be calculated using divot points. Table A3 summarizes the HPM locations.

Table A3 - Key reference points and lines

Reference Point or Line	Summary of Location
H-Point	The intersection of the cushion line and torso line corresponds to the pivot center of the cushion pan and back pan. This point is within the mechanism, and must be calculated using the divot points H1L and H1R or H2L and H2R. For additional accuracy, the divot points B1, B2, and C1 can be used to define the lateral centerline of the HPM.
D-Point	Located on the bottom of the cushion pan, at the lateral centerline, 25.5 mm (15 degrees) rearward of the H-point (when cushion angle equals 0). This point is identified by a divot point on the surface of the cushion pan (Figure A6). However, when the HPM is installed, this point cannot be reached and so must be calculated relative to the H-point.
Heel of Shoe	The heel point is found at the bottom of the back of the shoe, at the lateral centerline. It is used to define the accelerator heel point (AHP) for the driver, and the floor reference point (FRP) for passengers. The heel point cannot be reached when the HPM is installed. The location must be calculated using S1, S2, and S3 divot points.
Ball of Foot (BOF)	The ball of foot (BOF) is located on the bottom of the shoe, at the lateral centerline, 203 mm from the heel point. It is used to define the ball of foot reference point (BOFRP) for the driver. BOF on the shoe tool is located at the zero marking (corner) of the two scales on the top surface of the shoe. A more precise location can be calculated using S1, S2, and S3 divot points.
Torso line	A line from the H-point through the sliding thoracic pivot (B1 divot point).
Cushion Line	A line from the H-point through the C1 divot point.
Thigh Line	A line from the H-point through the knee pivot K1.
Leg Line	A line from the knee pivot K1 through the ankle pivot S1.
Bottom of Shoe	A line in side view from the heel of shoe through the BOF. The angle of this line from horizontal defines the shoe plane angle (driver) or floor plane angle (passengers).
Bare Foot Flesh Line	A line originating from a point 286.9 mm from the heel of shoe, on the bottom of shoe line, at a 6.5 degree angle. This line is provided on the HPD, but not on the HPM.

A.3.5 Posture Angles and LSP

The HPM can be used to determine posture angles. Several angles are summarized in Table A4. The methods for taking the measurements refer to reference lines, divots, and lands. Torso and cushion angles, as well as lumbar support prominence, can be measured without installing the legs. Other angles in Table A4 require installation of the legs and shoe tool (see Figures A7 and A8).

Table A4 - Posture angles and LSP

SAE J1100 Code	Posture Angle	Location and Measurement
A40	Torso Angle	The angle of the torso line from vertical defines the torso angle. The torso angle can be measured by H1 (or H2) and B1 divots, or by placing the inclinometer on the torso angle land on the back pan assembly, or by the torso angle land on the head room fixture with the fixture mounted flush to the back pan assembly.
A27	Cushion Angle	The angle of the cushion line from horizontal defines the cushion angle. The cushion angle can be measured using H1 (or H2) and C1 divots, or by placing the inclinometer on the cushion angle land on the cushion pan assembly.
A57	Thigh Angle	The angle of the thigh line from horizontal defines the thigh angle. Thigh angle can be measured by using knee pivot K1 and the H-point (H1 or H2 divot), or by placing the inclinometer on the thigh angle land on the thigh assembly. Cushion and thigh angles are independent.
A42	Hip Angle	The angle between the torso and thigh lines defines the hip angle. After the thigh and torso angles are measured, the hip angle can be calculated: Hip angle = 90 degrees + torso angle - thigh angle.
A44	Knee Angle	The angle formed by the intersection of the thigh line and the leg line defines the knee angle. A direct read-out scale is provided on the leg segment. The angle can also be calculated using divot points S1, K1, and H1 or H2.
A46	Ankle Angle	The angle between the lower leg and the bare foot flesh line forms the ankle angle. A direct read-out scale is provided on the shoe assembly.
A47, A48	Shoe Plane Angle or Floor Plane Angle	The angle from horizontal to the bottom of the shoe forms the shoe plane angle or floor plane angle. The angle can be determined by using divot points S3 and S2, or by placing an inclinometer on the shoe plane and on the shoe.
L81	Lumbar Support Prominence (LSP)	LSP is defined as: $LSP = 57 \text{ mm} - X$ where: X is the distance between the lumbar-pelvic pivot to the torso line, measured normal to the torso line. In the neutral posture LSP equals zero so that the back pan has a flat lower back similar to the original H-point machine; the distance between the lumbar-pelvic pivot and the torso line is 57 mm. As LSP increases, the lumbar segment of the back pan assembly is pushed forward, the pelvic and thoracic segments are tipped, and the lumbar-pelvic pivot moves closer to the torso line (see Figure A9). For measurement, a direct read-out scale is provided on the back pan assembly.

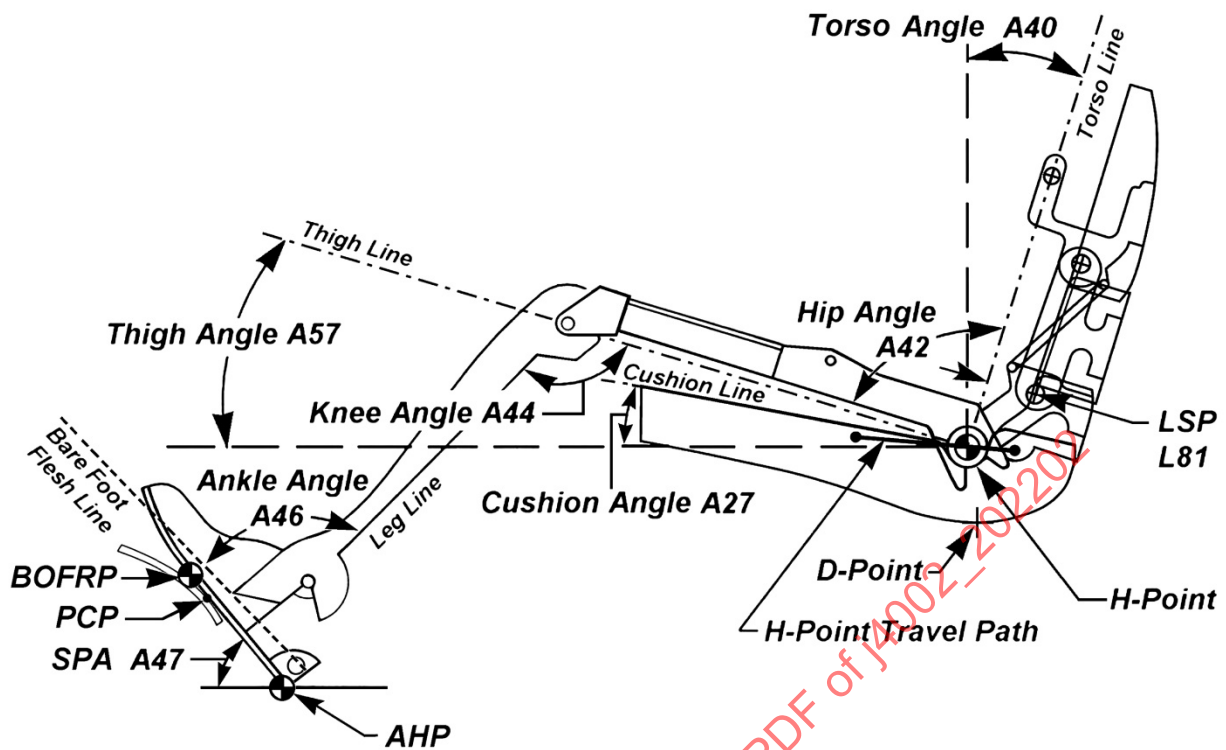


Figure A8 - Reference points, reference lines, and posture angles

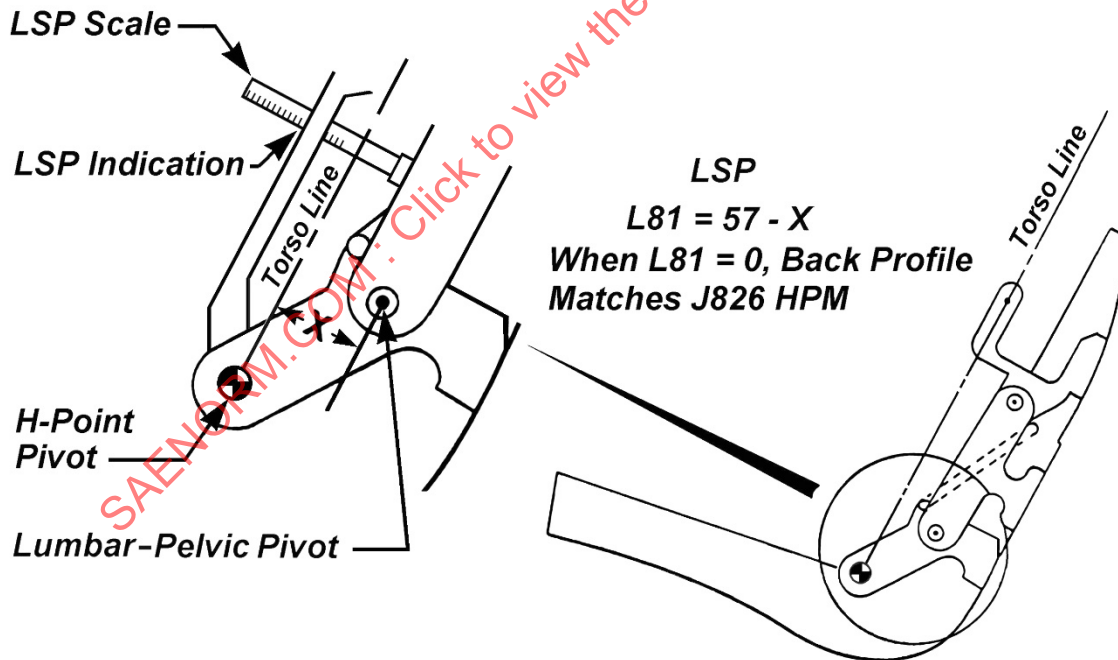


Figure A9 - Lumbar support prominence (LSP)

APPENDIX B - (INFORMATIVE) HPM SPECIFICATION AND TOLERANCES

B.1 TOLERANCES

The following comments apply to all tolerances given in the tables of this appendix.

HPM tolerances reflect an acceptable dimensional variation that would not affect the overall performance measurements of the H-point machine. If conditions of use, wear, or damage result in measurements that exceed the specified tolerance values, the HPM should be recalibrated.

The build tolerances of the HPM as produced by the HPM manufacturer are well below the tolerances specified in these tables.

B.2 REFERENCE POSTURE FOR SPECIFICATIONS

Unless otherwise specified, all dimensions in this section are given in true vertical or true horizontal, with the device postured using the settings in Table B1 (see Figure B1).

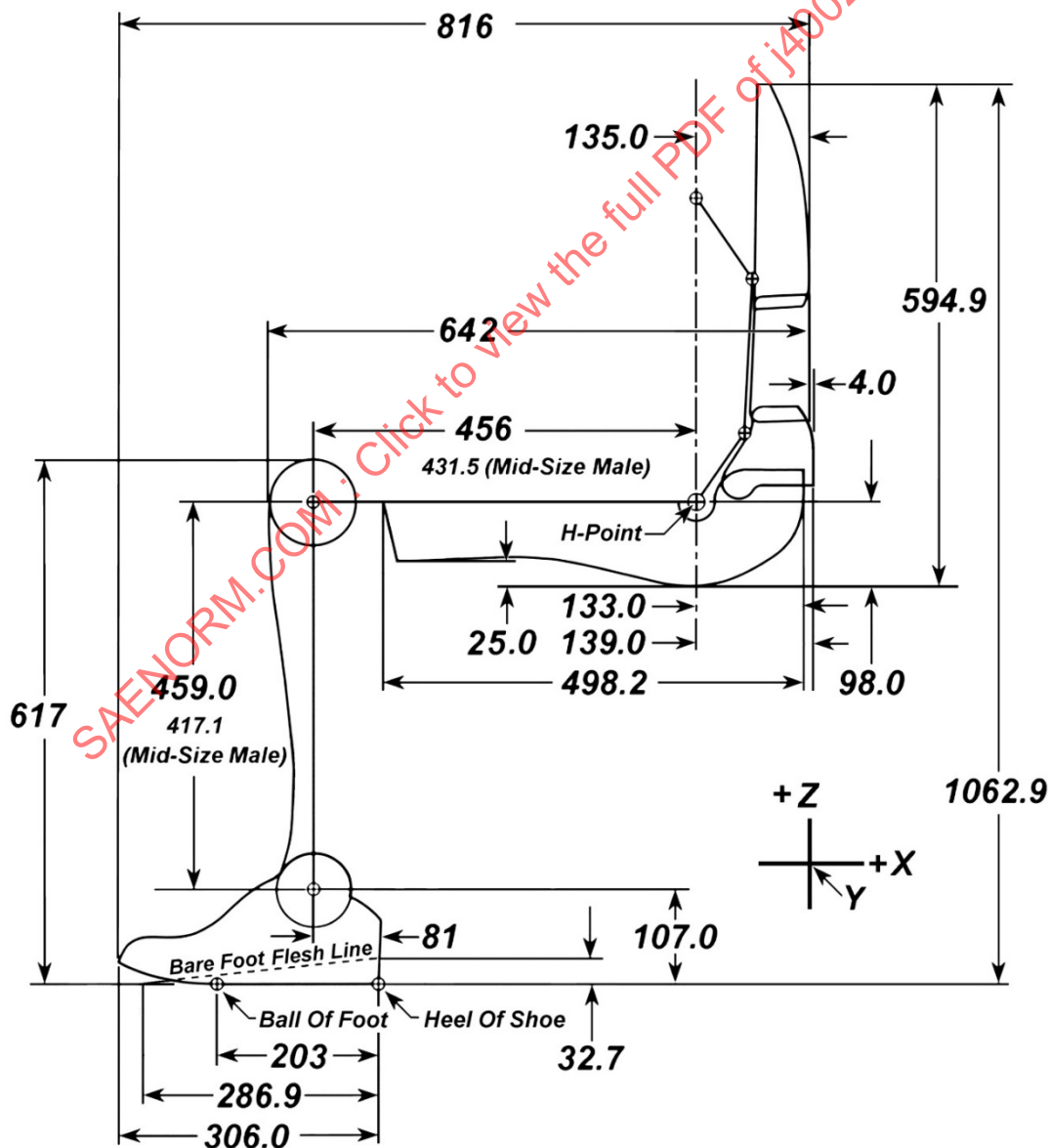


Figure B1 - HPM lengths and heights, side view

Table B1 - Posture of HPM for specifications

Dimension	Value	
Torso Angle	0	degrees
LSP	0	mm
Cushion Angle	0	degrees
Thigh Angle	0	degrees
Knee Angle	90	degrees
Ankle Angle*	96.5	degrees
Thigh Length	456	mm (SgRP)
Lower Leg Length	459	mm (SgRP)

* The bottom of the shoe is flat on the XY plane. However, since ankle angle is measured from the bare foot flesh line, and not the bottom of shoe, the ankle angle will be 96.5 degrees, not 90 degrees.

B.3 SHOE TOOL DIMENSIONS

See Table B2.

Table B2 - Shoe tool dimensions

Dimension	Value
Overall Length of Shoe	306 mm
BOF to HOS Distance	203 mm
Ankle Pivot	107 mm above HOS 81 mm forward of HOS
Bare Foot Flesh Line	6.5 degrees above the bottom of shoe; originates in shoe plane 286.9 mm forward of HOS
Relative to BOF	9.9 mm above
Relative to HOS	32.7 mm above

B.4 LENGTHS

See Table B3 and Figure B1.

Table B3 - Lengths (in millimeters)

Description	Value	HPM Tolerance
Overall (Rearmost to Foremost)	816.0	±4.0
Overall, not Counting Shoe	642.0	±4.0
Cushion Pan	498.2	±4.0
Shoe	306.0	±2.0
Heel of Shoe to Ball of Foot	203.0	±2.0
Heel of Shoe to Ankle Pivot	81.0	±2.0
Heel of Shoe to Origin of Bare Foot Flesh Line	286.9	N/A
H-Point to Knee Pivot	456.0	±2.0
H-Point to Knee Pivot, w/ Mid-Size Male Leg Lengths	432.0	±2.0
H-Point to Back of Cushion Pan	133.0	±2.0
H-Point to Back of Back Pan	135.0	±2.0

B.5 WIDTHS

See Table B4.

Table B4 - Widths (in millimeters)

Description	Value	HPM Tolerance
Cushion Pan, Max (358 mm forward of H-Point)	405.8	±4.0
Cushion Pan, at H-Point	383.3	±4.0
Cushion Pan, at D-Point	371.0	±4.0
Cushion Pan, at CP2 Support Points	401.0	±4.0
Cushion Pan, at CP3 Support Points	405.1	±4.0
Back Pan, Max (442 mm above H-Point)	384.6	±4.0
Pelvic Segment, at BP1 Support Point	373.7	±4.0
Lumbar Segment, at BP2 Support Point	326.0	±4.0
Thoracic Segment, at BP3 Support Point	360.3	±4.0
Shoe, Max (at Ball of Foot)	110.0	±2.0

B.6 HEIGHTS

See Table B5 and Figure B1.

Table B5 - Heights (in millimeters)

Description	Value	HPM Tolerance
Overall	1062.9	±4.0
Seated Height (Bottom of Cushion Pan to Top of Device)	594.9	±4.0
Cushion Pan, Max	132.3	±4.0
Pelvic Segment, Max	94.9	±4.0
Lumbar Segment, Max	150.3	±4.0
Thoracic Segment, Max	255.6	±4.0
Lumbar-Pelvic Pivot to Bottom of Cushion Pan	180.8	±4.0
Thoracic-Lumbar Pivot to Bottom of Cushion Pan	363.5	±4.0
H-Point to Bottom of Cushion Pan	98.0	±2.0
Heel of Shoe to Ankle Pivot	107.0	±2.0
Heel of Shoe to Bare Foot Flesh Line	32.7	N/A
Ball of Foot to Bare Foot Flesh Line	9.9	N/A
Knee Pivot Point to Ankle Pivot Point	459.0	±2.0
Knee Pivot Point to Ankle Pivot Point, Mid-Size Male	417.5	±2.0
Knee Pivot Point to "Cross-Over" of Lower Leg Pieces	300.0	±1.0
Ankle Pivot Point to "Cross-Over" of Lower Leg Pieces	159.0	±1.0
Top of Knee to Bottom of Shoe	617.0	±2.0
Sole of Shoe	3.2	±1.0

B.7 RADII

The radius of the knee is 51 mm. The radius of the ankle on the shoe tool is 19.1 mm. The radius of the ankle curve at the lower end of the lower leg is 44.5 mm.

B.8 WEIGHT, HPM ONLY

See Table B6.

Table B6 - Weights (in kilograms)

Description	Value per Unit	Tolerance per Unit	Quantity
HPM w/o Weights	19.31	±0.35	1
Cushion Pan	8.41	±0.15	1
Back Pan	5.94	±0.10	1
Head Room Fixture	1.43	±0.03	1
Upper Leg	2.11	±0.03	1
Lower Leg	0.88	±0.02	1
Shoe	0.54	±0.02	1
HPM w/ Weights (Fully Loaded)	72.69	±1.20	1
Pelvic Weight, Plain	3.2	±0.05	4
Pelvic Weight, Beveled	3.13	±0.05	2
Thigh Weight	2.14	±0.03	6
Back Weight	1.79	±0.03	12

B.9 SUPPORT POINTS

Support points are located on the outer surface of the cushion pan (CP) and back pan (BP) contours. See Table B7 and Figure A6.

Table B7 - Support point locations (in millimeters)

Point	Quantity	Distance from H-Point		
		X ^a	Y	Z ^b
D-Point	1	25.5	0.0	-95.2
CP1	1	0.0	0.0	-98.0
CP2	2	-125.0	±80.0	-78.2
CP3	2	-250.0	±110.0	-69.2
BP1	1	135.1	0.0	35.0
BP2	1	135.1	0.0	175.0
BP3	2	122.7	±90.0	350.0
HPM Tolerance	All support points	±4.0	±4.0	±4.0

^a Positive X values are rearward, negative values are forward of H-point.

^b Positive Z values are above, negative values are below H-point.

B.10 DIVOT POINT LOCATIONS

See Table B8.

Table B8 - Divot point locations

Divot	Location	HPM Description	HPM Tolerances
B1	550 mm above the H-point on the torso line	Located in the screw hole on the top of the back pan T-handle	±2.0
B2	330 mm above the H-point 35 mm forward of the torso line (and H-Point)	Located along the back pan centerline, in front of the sliding thorax pivot	±2.0
H1L H1R	200 mm to the left (H1L) or the right (H1R) of the measured H-point	Located at the ends of the H-point rod where the back pan and cushion pan are joined	±1.0
H2L H2R	25 mm inboard of the H1 divots; aligned with H1 divots in X and Z	Located near the end of the H-point rod in a cutout accessible from above	±1.0
C1	275 mm forward of the H-point on the cushion line	Located along the cushion pan centerline, in a hole on top of the push block	±2.0
K1L K1R	239 mm to the left (K1L) or right (K1R) of centerline, on the knee pivot axis	Used to define the K-Point location. The K1L and K1R provide the x, z coordinates, while K2 provides the y coordinate	±2.0
K2	50 mm forward of the knee pivot center (K-Point)		±1.0
S1L S1R	(x) 81 mm forward of heel of shoe, (y) ±10 mm to either side of the shoe centerline, (z) 107 mm above bottom of shoe	Located on either side of the ankle pivot (S1L is 10 mm to the left; S1R is 10 mm to the right)	±2.0 x ±0.5 y ±0.5 z
S2L S2R	(x) 81 mm forward of the heel of shoe, (y) ±10 mm to either side of the shoe centerline, (z) 5 mm above bottom of shoe	Located on top of the sole of the shoe below the ankle pivot (S2L is 10 mm to the left; S2R is 10 mm to the right)	±2.0 x ±0.5 y ±0.5 z
S3L S3R	(x) 175 mm forward of the heel of shoe, (y) ±10 mm to either side of the shoe centerline, (z) 5 mm above bottom of shoe	Located on top of the sole of the shoe, near the ball of foot (S3L is 10 mm to the left; S3R is 10 mm to the right)	±2.0 x ±0.5 y ±0.5 z

B.11 BACK PAN LINKAGE MECHANISM

See Table B9. The values provided are straight-line distances, in millimeters.

Table B9 - Back pan linkage distances on HPD (in millimeters)

Description	Value	Property
H-Point to Lumbar-Pelvic Pivot	100.0	These values remain constant regardless of posture/LSP setting.
Lumbar-Pelvic to Thoracic-Lumbar Pivot	183.0	
Thoracic-Lumbar Pivot to Sliding Thoracic Pivot	119.0	
H-Point to Sliding Thoracic Pivot	363.24	This value increases as LSP increases, and decreases as LSP decreases.
Upper Reverse Link to Thoracic-Lumbar Pivot	36.5	These values remain constant regardless of LSP. The reverse linkage constrains the movement of the back pan segments.
Lower Reverse Link to Lumbar-Pelvic Pivot	36.5	
Upper to Lower Reverse Link	159.3	

B.12 MUSLIN CLOTH

Place a piece of muslin cotton cloth over the seat area to be checked. The muslin cloth should be of sufficient size to prevent the machine from contacting the seat. The muslin should be a plain cotton, single weave fabric having a surface area density from 95 to 175 g/m². The muslin should be tucked in a sufficient amount to prevent hammocking of the material. If the test is run in a buck, suitable floor covering sections, or equivalent, are to be placed under the H-point machine's shoes.

B.13 CHECK THAT HPM IS WITHIN TOLERANCE SPECIFICATIONS

The HPM should be periodically checked to verify it is dimensionally accurate and functioning properly. It should be checked immediately if it appears to be functioning incorrectly, if it appears out of alignment, or if any misuse occurs. Some examples of misuse include:

- The HPM is dropped.
- The HPM is improperly loaded or assembled—or is improperly unloaded or unassembled—during use.
- The HPM is improperly moved or shipped. The HPM should be stored unassembled, with each piece protected and secured to prevent damage. It is recommended that the weights be stored separately.

A procedure for checking key elements of the HPM is given in Appendix C. The HPM should be repaired and rechecked whenever the tolerance specifications given in Appendix C cannot be met.

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APPENDIX C - (INFORMATIVE)
HPM FIELD CHECKING PROCEDURE

C.1 PURPOSE

This procedure can be used for checking the accuracy of the H-point machine (HPM) to determine if repairs are needed.

C.2 EQUIPMENT REQUIRED FOR CHECKING

C.2.1 User Provided Equipment

The user shall provide the following equipment:

- Flat, level surface (or surface plate) approximately 750 mm wide and 1000 mm long
- Two 90-degree angle blocks at least 200 mm wide, one approximately 150 mm high and a second approximately 100 mm high
- Two small C-clamps, one with 100 mm throat and one with 25 mm throat
- CMM equipment for taking the measurements
- HPM inclinometer

C.2.2 Checking Fixtures

Checking fixtures are available from SAE. Checking fixtures are described in the following sub-clauses and shown in Figure C1. Tolerances for surfaces on the fixtures and shims that affect the checking measurements are ± 0.05 mm.

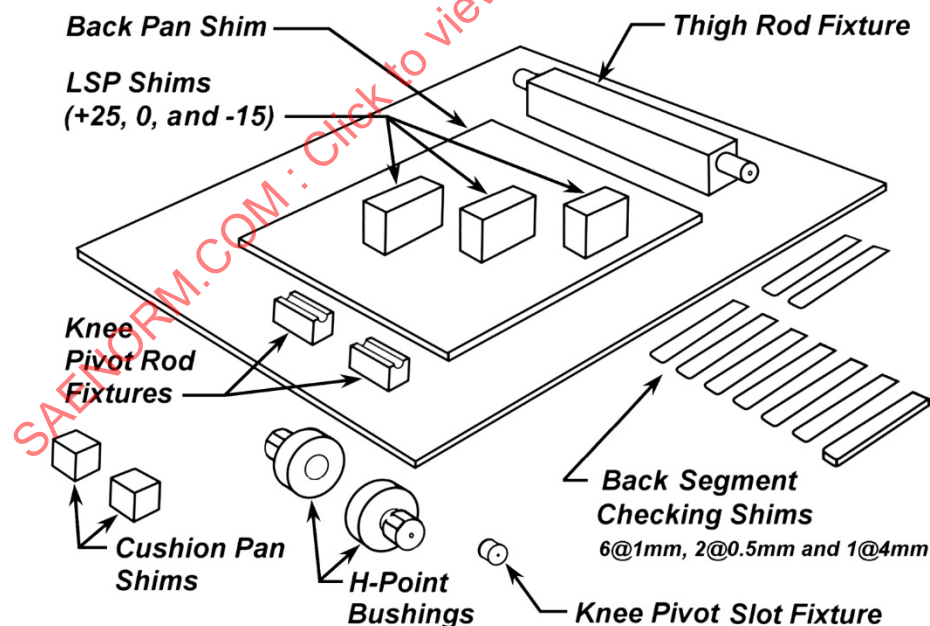


Figure C1 - Checking fixtures and shims

C.2.2.1 Cushion Pan Shims

Two 25 x 25 x 25 mm gage blocks used for leveling cushion pan.

C.2.2.2 LSP Shims

Gage blocks of a specified length (73.0 mm, 99.7 mm, and 46.8 mm) that fit between the two inclinometer lands on the back pan articulation rod. The three shims are used to position the back pan articulation mechanism at LSP scale readings of 0, +25, and -15.

C.2.2.3 Back Pan Shim

Rectangular shim used to support the back pan 4 mm above the flat level surface. The shim is approximately 250 mm wide and 400 mm long.

C.2.2.4 Back Segment Checking Shims

Two 0.5 mm thick shims, six 1 mm thick shims, and one 4 mm thick shim used to check pelvic segment clearance to the level surface and back pan gap between lumbar and thoracic segments. The shims are 25 mm wide and approximately 65 mm long.

C.2.2.5 H-Point Bushings

Two bushings that fit on each side of the back pan H-point pivot shaft (12 mm diameter holes) to provide a divot point for measuring H-point location and slots for inserting the head room probe H-point forks.

C.2.2.6 Thigh Rod Fixture

Fixture for providing H-point divots and supporting the H-point center (H1L and H1R) on the forks of the thigh segment at a height of 30 mm above the level surface. The diameter of the H-point rods extending from each side of the fixture is 12 mm.

C.2.2.7 Knee Pivot Rod Fixtures

Fixtures that support the knee pivot rod divots, K1L and K1R, 30 mm above the level surface. The diameter of the slot in the fixtures is 12.7 mm.

C.2.2.8 Knee Pivot Slot Fixture

Fixture that provides divot points for the knee pivot center (K1) on the leg segment knee pivot fork. The diameter of the knee pivot slot on the fixture is 12.7 mm.

C.2.3 Measurement Equipment

C.2.3.1 CMM

Points used to determine distance measurements shown in Table C1 and Section C.5 should be taken with a CMM. Angular measurements on the inclinometer lands are taken with both the inclinometer and a CMM. When CMM equipment is used to check angle measurements on the inclinometer lands, the digitized points taken on the lands should be separated by the length of the inclinometer (or greater) as shown in Figure C3.

The XYZ axis orientations to be used for recording CMM data are shown in Figures C4, C6, C7, C8, and C9. This provides a direction convention for both linear and angular measurements. Establish and maintain this axis orientation on the flat level surface used to position the HPM components. A positive angle is clockwise as viewed from the left side of the components. This angle convention is consistent with positive cushion angle and torso angle definitions.

C.2.3.2 Electronic Level (HPM Inclinometer)

Prior to checking the HPM place the inclinometer parallel to the X axis on the flat level surface used for testing and set the inclinometer reading to zero using the alt zero button. It is desirable to re-zero the inclinometer prior to each measurement taken. Use the information provided by the inclinometer manufacturer to check accuracy of the inclinometer. The inclinometer should be regularly checked and certified per manufacturer specifications.

C.3 HPM MEASUREMENT LOCATIONS

Most measurements specified in the checking procedures are taken to the HPM divot points and inclinometer lands shown in Figures C2 and C3. Divot points K2, S2, S3 and inclinometer lands on the bottom of the shoe are not used in the calibration procedure.

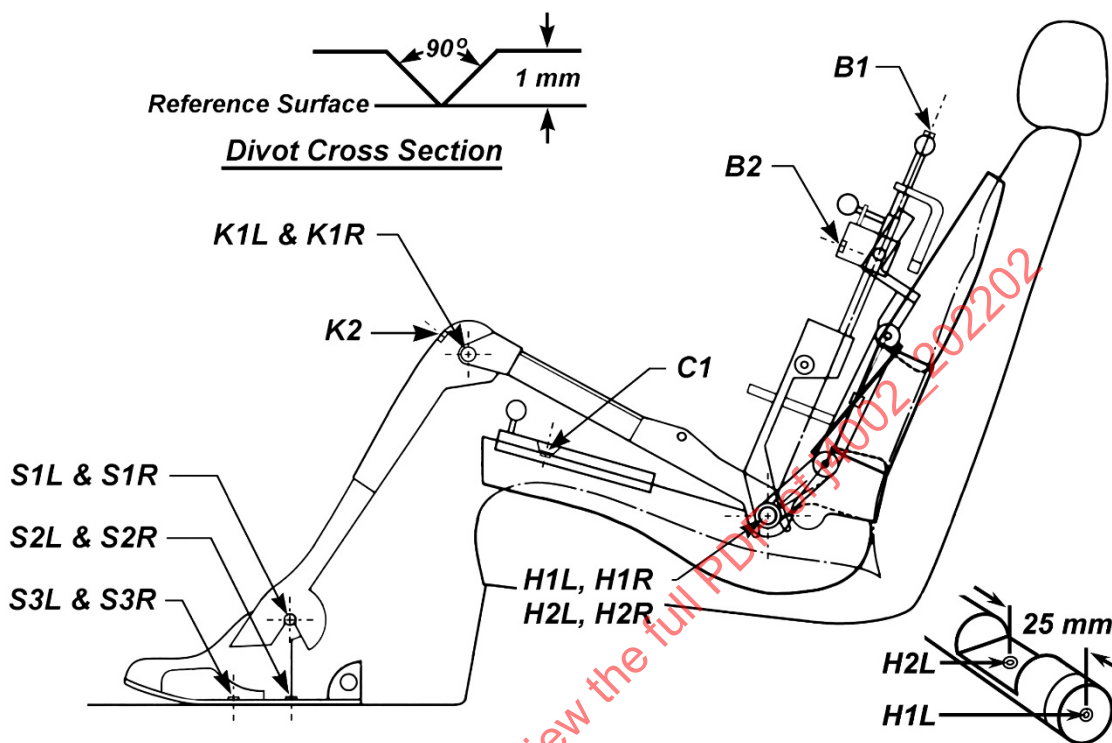


Figure C2 - HPM reference points (divot points)

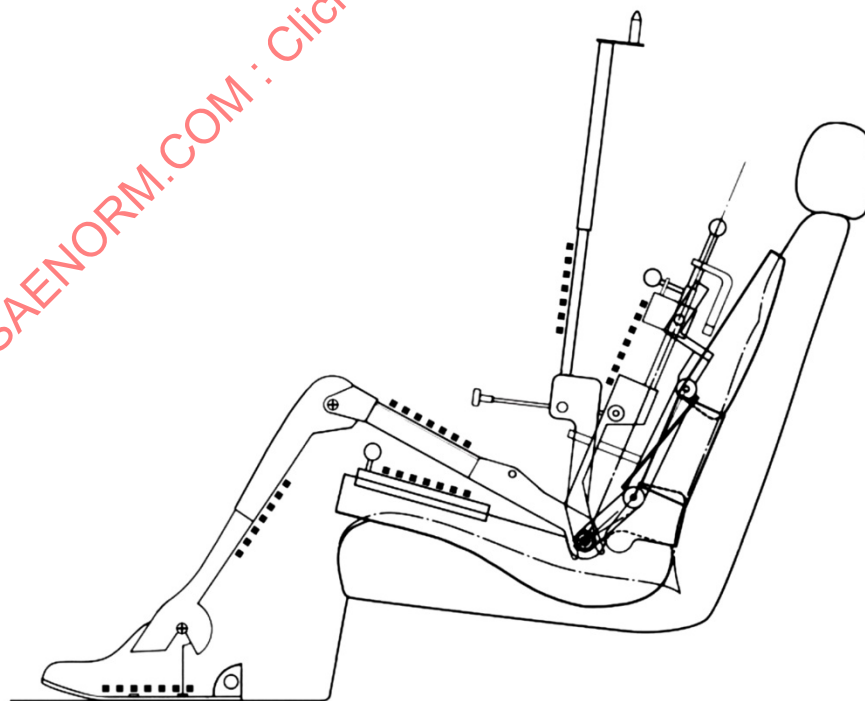


Figure C3 - HPM reference surfaces (inclinometer lands)