Technical Report Documentation Page

1. Report No. UMTRI-86-39

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle Study of Seatback Contours for Optimum Seat Design

5. Report Date 31 July 86

6. Performing Organization Code

7. Author(s)
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8. Performing Organization Report No. UMTRI-86-39

9. Performing Organization Name and Address
Transportation Research Institute
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10. Work Unit No. (TRAIS)

11. Contract or Grant No. P.O. 30542

12. Sponsoring Agency Name and Address
ITT Hancock Engineered Products
2300 E. Ganson Street
Jackson, Michigan 49204

13. Type of Report and Period Covered Final Report May 1986 - August 1986

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The University of Michigan Transportation Research Institute has conducted a study of seatback contours for optimum seat design. A particular emphasis was placed on selecting the proper location for lumbar support. One section of the report reviews the data base for selecting deformed seatback contours. The other section makes recommendations for deformed seatback contours for small female, mid-sized male, and large male automobile occupants. This includes a provision for including lumbar support. The report is supplemented by two full-scale blueprints showing the data base and the recommended curves.

17. Key Words
Seating
Ergonomics
Lumbar Support
Seating Comfort

18. Distribution Statement Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
None	None	12	

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STUDY OF SEATBACK CONTOURS FOR OPTIMUM SEAT DESIGN

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31 July 86

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1.0 INTRODUCTION

The University of Michigan Transportation Research Institute (UMTRI) has conducted a study of seatback contours for optimum seat design. The following two sections of this report review the data base for selecting deformed seatback contours and recommend contours which may be selected as design goals for small female, mid-sized male, and large male automobile occupants.

2.0 REVIEW OF THE DATA BASE

Of the many studies of seating posture and comfort, only a very few contain or utilize data which quantitatively describe the geometry of the human back. Much of this work is quite recent and it is estimated that many new results will be forthcoming in the next several years.

Four research studies have concentrated on the geometry of the pelvis and spine as they are oriented in an automobile seat. Dempster (1955) located the hip joint (H-point) directly below the anterior-superior iliac spines, one-half the distance to the surface of the seat. This implies a fixed orientation of the pelvis with respect to the seat. Similarly, in work which led directly to the H-point machine (See SAE Standard, J826) used in automotive design, Geoffrey (1961) located the H-point 5.28 inches in front of the seat back and 3.84 inches above the seat pan. Geoffrey's work was based on an analysis of x-rays taken on subjects seated in automobiles. Recent work by Schneider et al (1983) determined the shape of the exterior interface between a car seat and the occupant. Robbins (1983a) estimated the location of the interior skeleton through a detailed analysis of photographs taken of subjects seated in automobile seats.

These four studies used different techniques to locate the skeleton within the seated body. Discrepancies in results are still present. Data, not yet analyzed, are available to reconcile the work of Robbins with that of Geoffrey and the H-point machine.

An additional study by Hubbard and Reynolds (1984) uses an approach similar to Robbins in order to show what happens to posture when the curvature of the spine more closely represents an erect standing person. This posture apparently yields a higher location for the eyes than that obtained for the normal seated occupant.

The well known design tool, Humanscale 1/2/3 by Diffrient, et al (1974) includes recommendations which are largely based on the SAE Standard, J826. In addition, this tool assumes seat cushion compression of 0.25 inches for every 30 lbs of body weight. It also recommends that lumbar support be applied 9-10 inches above the deformed seat plane.

The value for seat compressibility is relatively similar to data available at UMTRI for both a major domestic and a major Japanese manufacturer. Many European seat cushions tend to be stiffer. Also, no seat is believed to be truly linear.

The location of the most comfortable lumbar support (based on a correlation with peak pressure between the back and the support) has been confirmed by Kamijo, et al (1982) of Nissan to be about 10 inches above the seat cushion. This support should be provided over the entire lumbar region - a length of about 4 inches. It should be centered at about the middle of the lumbar spine. Additional support should be provided for the sacrum and thorax regions, but at lower pressure. Guidelines have been presented in the Humanscale design tool defining the general region of the back and seat cushion where support should be provided.

Two additional studies, not directly used in this work, should be mentioned. Weichenrieder and Haldenwanger (1985) of Audi AG have written an excellent overview of the function of a car seat. Some of the data on body angles may be of use in defining angles of the extremities for the various sizes of occupants in adjustable seats. Branton (1984), in his study of backshapes of seated persons, has found that it is very difficult to select a single, completely acceptable, curve of the back. The variations among sitters is very great leading to major difficulty for the designer.

3.0 PREFERRED DEFORMED SEAT PROFILES

3.1 Graphical Presentation of the Data Base

In order to choose preferred deformed seat profiles it was necessary to develop, insofar as possible, a geometric definition of the human interior bony skeletal structure in the likely postures assumed by occupants of car seats. The location of the lumbar spine was of particular interest in order to recommend the location for placement of lumbar support.

Three of the references discussed in Section 2 provided information relating the surface geometry of a seated vehicle occupant to location of the interior bony spinal column. These were the reports by Robbins (1983a,1983b) and the paper by Hubbard and Reynolds (1984). In addition, the paper by Kamijo et al (1982), an evaluation of seating comfort, measured the distance above the seat cushion at which maximum pressure is applied to the back. Conclusions were reached indicating the optimum location for lumbar support. Similarly, Humanscale (Diffrient et al, 1974), made recommendations for the location and extent of lumbar support for automobile seats. Finally, SAE Standard J826, which defines the H-point machine, uses results from a study by Geoffrey (1961) of the posture of human volunteers seated in car seats. That study estimated a location for the center of the hip joints.

In order to study the relation among the various data resources just described, the following curves and data points were superimposed by merging the H-points (See Figure 1).

- small female, mid-size male, and large male from Robbins (1983a,1983b)
- the estimated location and orientation of the pelvis bone and the surface locations of the spinous processes of the 5th lumbar and 12th thoracic vertebrae
- various similar important points from the work of Hubbard and Reynolds (1984)
- the H-point machine profile for a 22° seatback and an 18° seat cushion

It should be noted that the seatback and seat cushion angle selections were arbitrary. They were added to show the relation between the profile of the standard design tool and seated humans. It should also be noted that the seatback angles used in the work reported by Robbins were a few degrees larger (as defined by H-point machine measurements). The data reported by Hubbard and Reynolds were a recommended construct for vehicle occupant comfort.

Additional information was added to Figure 1 from the Humanscale design package. This provided the location of points 9 and 10 inches (22.9 and 25.4 cm) above the seat cushion for lumbar support location. As a supplement and check, data from Kamijo et al (1982) were extracted to define the distance above the H-point where maximum pressure was applied to obtain maximum comfort.

Points shown on Figure 1 that have been obtained directly from these data sources include:

- Knee joints (1,2,4), spinous process surface target point for the fifth lumbar vertebra (15,16,17), spinous process surface target point for the twelfth thoracic vertebra (18,19,20), and H-points merged for all three human sizes, from Robbins (1983a, b).
- Knee point (3) and H-point from SAE Standard J826.
- Pelvic definition points including the ischiale (9), symphysion (10), and anterior superior iliac spine (11); spinous process surface target point for the fifth lumbar vertebra (12,13,14); spinous process surface target point for the twelfth thoracic vertebra (21,22,23), and head points including spinous process surface target point for the seventh cervical vertebra (27), back of the head (28), and top of the head (29); all from Hubbard and Reynolds (1984).
- 9 and 10 inch lumbar support points (24,25) from Humanscale (1974).
- Lumbar support point (26) from Kamijo et al (1982).

Several observations can be made about the relationships of the various points:

1. The maximum seat cushion penetrations for all the curves are in a relatively similar location when measured forward from the seatback. This location is related to the ischiale points on the pelvis which are virtually identical for both Robbins and Hubbard, et al.

2. The shape and orientation of the pelvis are virtually the same for both Robbins and Hubbard, et al as shown by comparing point numbers 9,10, and 11 on Figure 1 with the tracing of the pelvis. This provides a common starting point for the attachment of the lumbar spine to the pelvis in that three points on a body can be used to define its orientation in space.

3. The surface landmarks associated with the 5th lumbar vertebra (points 12,...,17) differ in their front to rear position but are located almost the same distance above the H-point. The positions measured by Robbins (points 15,16,17) represent a slumped posture in standard automobile seats, while the Hubbard and Reynolds points (12,13,14) are for a preferred posture based on spinal curvature for an adult in the standing position.

4. As would be expected, the locations for the 12th thoracic vertebra (points 18,...,23) vary with the height of the occupant, with those for the large male being the furthest above the H-point (points 19 and 22). Again the points given by Hubbard and Reynolds (21,22,23) are forward from those of Robbins (18,19,20) reflecting a more erect posture and a seatback with a smaller angle.

5. The back line given by the H-point machine is mostly between the data of Robbins and Hubbard.

6. The desired locations for lumbar support, given independently by Humanscale (1974) and Kamijo (1982), appear to be in similar positions in Figure 1 (points 24,25,26).

3.2 Justification for Assumption that Merging of H-points is not Unlike the Real Situation for All Occupant Sizes

Initially, the various seat interface curves for three basic occupant sizes were arbitrarily merged at the H-point. Figure 1 shows that the penetration into the seat cushion is larger as occupant sizes becomes larger. The penetration is labeled as points 6,7, and 8. The question arose as to how this qualitative observation was related to actual quantitative data.

Humanscale indicated cushion stiffnesses of 120 lb/in for automobile seats. A comparison was made with available data from two automobile companies (one domestic and one foreign). Both these sources indicated that the Humanscale data were not unrealistic until the cushion began to bottom out. This increase in stiffness was not significant until the weight of the large male was exceeded. Table 1 shows seat penetration based on the 120 lb/in stiffness for the three occupant sizes.

TABLE 1. SEAT PENETRATION (120 LB/IN or 21.5 kg/cm STIFFNESS

occupant	weight, lb (kg)	penetration, in (cm)
small female (SF)	104 (47.3)	0.87 (2.2)
mid-size male (MM)	169 (76.8)	1.41 (3.6)
large male (LM)	226 (102.7)	1.88 (4.8)

It was not possible to compare the predicted seat cushion penetrations directly with the profiles shown in Figure 1 as they are not based on a particular seat. However, the relationships between the change in penetration from one occupant size to the next could be compared. In order to do this the lowest point on the large male curve was located (point 8). It should be noted that this point was also below the low point for the mid-size male. The distances between the three curves along a vertical line through the low point on the large male curve were measured. These values are compared in Table 2 with similar values computed from the numbers presented in Table 1.

TABLE 2. SEAT PENETRATION COMPARISONS

	Prediction in (cm)	Merged H-points in (cm)	Points on Figure 1
SF to MM	0.54 (1.4)	0.85 (2.2)	6 to 7
MM to LM	0.47 (1.2)	0.40 (1.0)	7 to 8
Total (SF to LM)	1.01 (2.6)	1.25 (3.2)	6 to 8

It should be noted that although the ratios of SF to MM and MM to LM penetration change along the seat bottom, the overall 1.25 inch difference between SF and LM is nearly constant over the range of high pressure seat cushion loading. The difference between the predicted penetration difference of 1.01 inch and that observed when H-points are merged (1.25 in) is believed to be small considering seat cushion nonlinearities. Also tending to support this result is the fact that the large male is broader and heavier in contrast to the small female. The unexpected result of this simple analysis is that for seat cushions with stiffnesses generally in the range of 120 lb/in (21.5 kg/cm), the H-points for a large range of occupant sizes can be merged for use in a study of lumbar support placement along the seatback.

3.3 Development of Preferred Deformed Seat Profiles

To produce forward curvature in the lumbar spine, the maximum pressure should be applied at about the middle of the region between the 5th lumbar and 12th thoracic vertebrae. In other words, the center of any support pad should be located at this same location along the lumbar spine for any size occupant. This location is given by both Kamijo, et al (1982) and Diffrient (1974) in Humanscale as points 24, 25, and 26 in Figure 1. As the Kamijo and 10 inch points are nearly coincident, the 10 inch point (25) has been selected for use in development of preferred deformed seat profiles.

For the three sizes of subjects, the approximate distances between the 5th lumbar and 12th thoracic vertebrae, as defined by distance between surface markers, are:

- small female lumbar length (4.88 in, 12.4 cm) (point 14 to 23)
- mid-size male lumbar length (6.14 in, 15.6 cm) (point 12 to 21)
- large male lumbar length (7.33 in, 18.6 cm) (point 13 to 22)

It should be noted that these lengths are based on Hubbard and Reynolds (1984) data for the erect spine. The distance from the 5th lumbar vertebra target to the 10 inch line is as follows for the three occupant sizes.

- small female, 3.72 in (9.4 cm)
- mid-size male, 3.64 in (9.2 cm)
- large male, 3.08 in (7.8 cm)

The 10 inch line has been defined based on the distance along the seat back from a line tangent to the bottom of the SAE J826 manikin which is parallel to the upper leg. This bottom line goes through point 5 which is 3.87 inches below the H-point, a distance developed by SAE and used by Humanscale. The 10 inch line passes through point 25 and is perpendicular to the seat back line which is 22 degrees from the vertical. To provide the optimum placement of the lumbar support in the center of the lumbar region, it would be necessary to adjust the height of the H-point (or seat cushion) or the lumbar support. The center of the lumbar region for the three occupant sizes is shown in Figure 1 as points 30,31, and 32. The adjustments are simply the distance of the lumbar midpoints to the 10 inch line. They are shown as three bold lines on Figure 1. Numerically, the shifts are:

- small female, 1.27 in (3.3 cm) up
- mid-size male, 0.54 in (1.4 cm) up
- large male, 0.59 in (1.5 cm) down

If the location of the lumbar support were adjustable, the direction of the adjustments just given would be reversed. This also implies that the concept of a split frame seat could be useful in providing improved seating comfort. In this concept, seat cushion vertical adjustment is independent from the seat back. Considering all the assumptions, the placement of a lumbar support centered at the 10 inch (25.4 cm) point appears to be fairly reasonable for all occupant groups.

The recommended size for the lumbar support (Diffrient, 1974) is a 4 inch (10.2 cm) high pad which induces curvature in the spine to a depth of 0.6-1.5 inches (1.5-2.5 cm). However, in view of the fact that some people prefer to have no lumbar support, or may want it some days, and not others, the recommendation of the current investigator is for a smaller amount 0.6in(1.5 cm) unless an adjustable lumbar support system is installed. In that case, lumbar penetration capacity of up to about 1.5 inch (2.5 cm) could be recommended.

Figure 2 is a seating design aid for the implementation of lumbar support. It is based on the seat/occupant interface implemented in the H-point machine and the related flat manikin. This tool was selected because of its widespread use and also because it is based on human data (Geoffrey, 1961). The seat back angle (26°) is that of a specific split frame seat considered during the project.

Superimposed on the backline of the manikin shown in Figure 2 is a lumbar indentation based on the analysis which has just been presented. The 4-inch lumbar region is indicated. Also, Humanscale recommends additional thoracic support upward from this region and sacrum support downward in order to blend the lumbar indentation with the back line. The pressure applied in these additional two regions should be less than that applied in the lumbar region as demonstrated by Kamijo, et al (1982).

The location of the three seat bottoms is based on the upward shifts of the original H-point for the small female and mid-size male and the downward shift of the large male which have been described above. The original H-point is included for reference.

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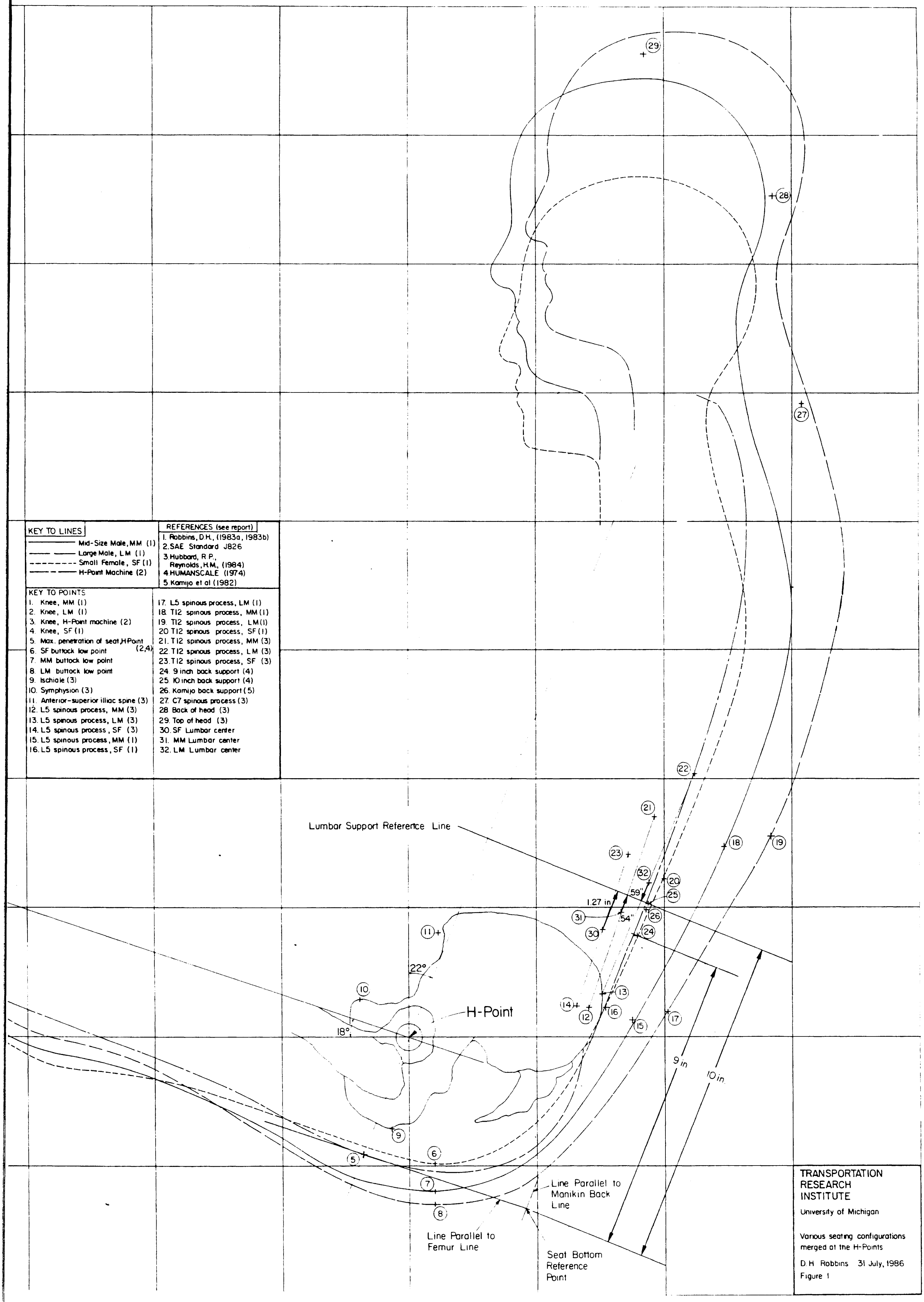

KEY TO LINES
Mid-Size Male, MM (1)
Large Male, LM (1)
Small Female, SF (1)
H-Point Machine (2)
REFERENCES (see report)
1. Robbins, D.H., (1983a, 1983b)
2. SAE Standard J826
3. Hubbard, R.P., Reynolds, H.M., (1984)
4. HUMANSCALE (1974)
5. Kamijo et al (1982)
KEY TO POINTS
1. Knee, MM (1)
2. Knee, LM (1)
3. Knee, H-Point machine (2)
4. Knee, SF (1)
5. Max. penetration of seat, H-Point (2,4)
6. SF buttock low point
7. MM buttock low point
8. LM buttock low point
9. Ischiale (3)
10. Symphysion (3)
11. Anterior-superior illiac spine (3)
12. L5 spinous process, MM (3)
13. L5 spinous process, LM (3)
14. L5 spinous process, SF (3)
15. L5 spinous process, MM (1)
16. L5 spinous process, SF (1)
17. L5 spinous process, LM (1)
18. T12 spinous process, MM (1)
19. T12 spinous process, LM (1)
20. T12 spinous process, SF (1)
21. T12 spinous process, MM (3)
22. T12 spinous process, LM (3)
23. T12 spinous process, SF (3)
24. 9 inch back support (4)
25. 10 inch back support (4)
26. Kamijo back support (5)
27. C7 spinous process (3)
28. Back of head (3)
29. Top of head (3)
30. SF Lumbar center
31. MM Lumbar center
32. LM Lumbar center
Lumbar Support Reference Line
1.27 in
.59"
.54"
22°
18°
H-Point
9 in
10 in
Line Parallel to Manikin Back Line
Line Parallel to Femur Line
Seat Bottom Reference Point
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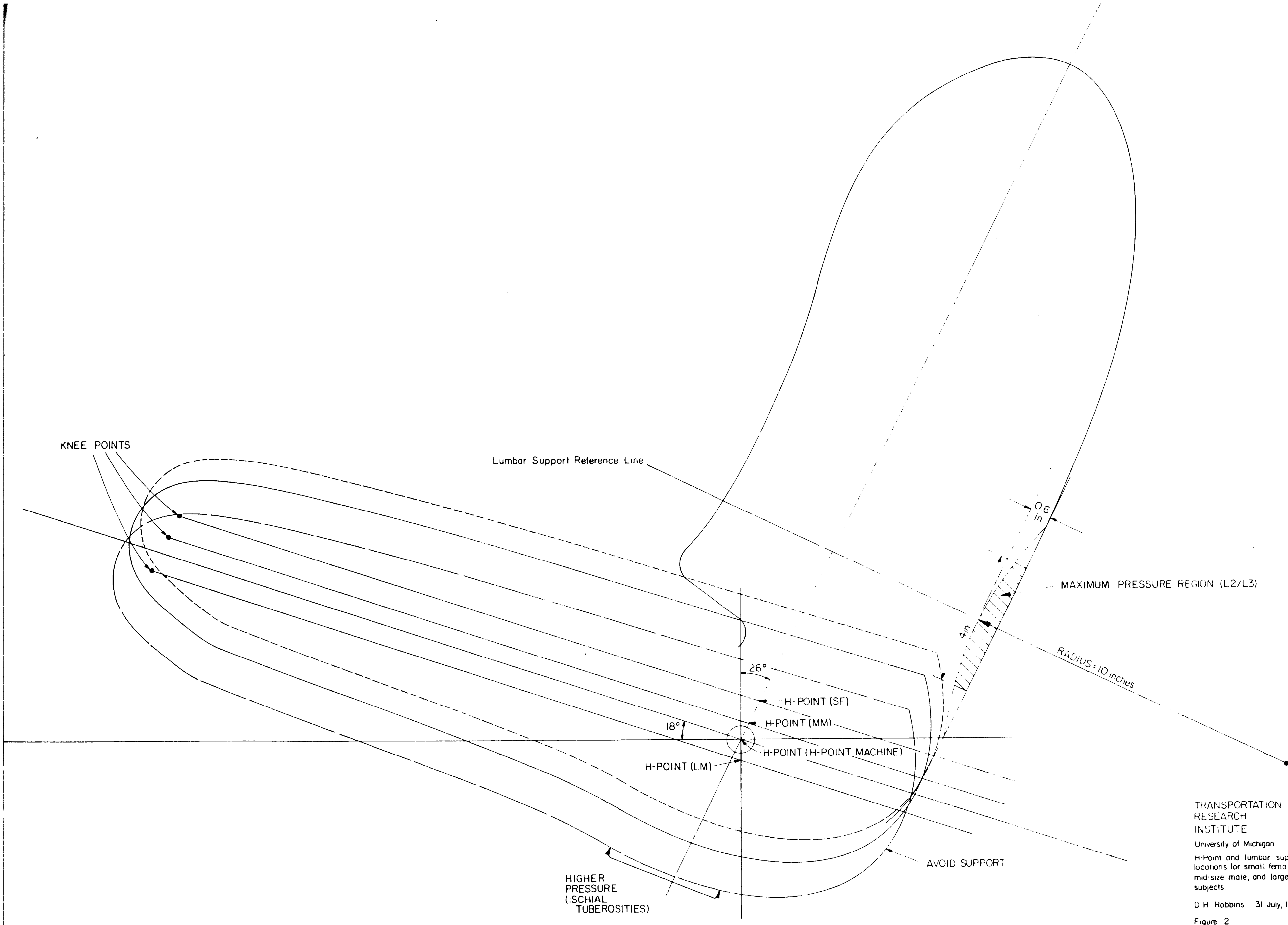
Various seating configurations merged at the H-Points
D.H. Robbins 31 July, 1986
Figure 1



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H-Point and lumbar support locations for small female, mid-size male, and large male subjects

D H Robbins 31 July, 1986

Figure 2