UMTRI-95-13

Design Criteria for Automobile Seatbacks Based on Preferred Driver Postures

TECHNICAL REPORT

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Submitted to:

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March 31, 1995

Technical Report Documentation Page

1. Report No. UMTRI-95-13	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle DESIGN CRITERIA FOR AUTOMOBILE SEATBACKS BASED ON PREFERRED DRIVER POSTURES	5. Report Date March 31, 1995
	6. Performing Organization Code
7. Authors Matthew P. Reed and Lawrence W. Schneider	8. Performing Organization Report No. UMTRI-95-13
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute 2901 Baxter Road Ann Arbor, Michigan 48109-2150	10. Work Unit No.
	11. Contract or Grant No. 391363
12. Sponsoring Agency Name and Address Lear Seating Corporation 21557 Telegraph Road Southfield, MI 48034	13. Type of Report and Period Covered Technical Report
	14. Sponsoring Agency Code

15. Supplementary Notes

M.P. Reed, L.W. Schneider, and B.A.H. Eby, *The Effects of Lumbar Support Prominence and Vertical Adjustability on Driver Postures*. Final Report No. UMTRI-95-12. Ann Arbor, MI: University of Michigan Transportation Research Institute, March 1995.

16. Abstract

This report presents lumbar support design recommendations for auto seats based on data from a recent study of preferred driving posture. Specifications and methods for determining seat contours are presented for both fixed- and adjustable-contour seats. Techniques for evaluating the success of the design are discussed.

17. Key Words Automotive Seating, Comfort, Seat Design Recommendations, Lumbar Support	18. Distribution Statement Unlimited

19. Security Classif. (of this report) None	20. Security Classif. (of this page) None	21. No. of Pages 42	22. Price

Reproduction of completed page authorized

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1.0 INTRODUCTION

Most previous seatback design recommendations have been based on physiological rationales intended to reduce lower-back stresses. However, research has not demonstrated that lumbar supports designed to these specifications actually produce the intended postures. In a recent laboratory study (Reed *et al.* 1995), the preferred driving postures of volunteer subjects who were selected to be representative of the driving population were measured. The lumbar support geometry of the test seat was varied to determine the effects of changes in lumbar support prominence and vertical adjustability on preferred driving position.

These data form the basis for the design recommendations presented in this supplementary report. Specific recommendations are made for the design of seatbacks for the U.S. driving population with the goal of providing optimal support for drivers' preferred postures. Section 2 presents a brief discussion of some of the relevant human anatomy and terminology used in discussing relationships between the sitter's body and the seat, as well as a brief summary of the relevant findings of the recent study. Section 3 contains specific recommendations for the design of fixed- and adjustable-contour seatbacks, with emphasis on lumbar support. Section 4 presents a brief discussion of testing procedures that should be used to assess the performance of a lumbar support design. Appendices A and B contain tabular documentation of preferred back contours and a generic undepressed seat contour on which designs may be based.

2.0 BACKGROUND

2.1 RELEVANT ANATOMY AND TERMINOLOGY

Figure 1 illustrates the typical position and orientation of the pelvis and lumbar spine in an auto seat. This figure is intended to show the relative positions of the pelvis and vertebral bodies, although the shapes of the structures have been simplified. The dimensions used to construct this figure are approximately those of a midsize U.S. male, 50th percentile by stature and weight. There are, of course, considerable variations in the skeletal dimensions even among individuals who match those characteristics. Schneider *et al.* (1985) and Robbins *et al.* (1985a, 1985b) are sources of more specific information regarding population norms and variability in auto-seated anthropometry.

Figure 1 illustrates the important components of the skeleton that will be referred to in this report. The thorax is the upper part of the torso, generally delineated by the ribcage. The thoracic spine consists of 12 vertebrae referred to as T1 through T12. The spinous processes are the bony prominences at the back of each vertebrae that can be palpated through the skin. Because the tissue over these points is relatively thin, they can be reliably palpated to determine the position of the spine. Two ribs (one on each side of the body) attach to each thoracic vertebra. At the front of the chest, the first 10 ribs on each side attach via costal cartilage to the sternum, a vertically-oriented, relatively flat bone at the front of the chest. The angle of the sternum provides a useful and reliable measure of the spatial orientation of the thorax.

The pelvis is comprised of two symmetrical hip bones connected anteriorly at the pubic symphysis and posteriorly by the sacrum. Each hip bone consists of three fused bones: the ilium, pubis, and ischium. The superior edge of each ilium forms a prominent ridge called the iliac crest. The pubis bones connect the ilia together via the pubic symphysis, while the ischia form the rocker-shaped structures at the bottom of the pelvis that are the primary skeletal load-bearing surfaces in sitting. The sacrum consists of five fused vertebrae at the base of the spinal column. The sacroiliac joints on either side of the sacrum connect the sacrum to the hip bones (ilia).

The lumbar spine lies between the thoracic spine and sacrum and consists of five vertebrae referred to as L1 through L5. The lumbar intervertebral joints have considerably more mobility than the joints in the thoracic spine, so changes in orientation between the thorax and pelvis result primarily from flexion or extension of the lumbar spine. Flexion refers to the spine movement in the sagittal (side-view) plane that occurs when the sitter bends forward at the waist (*i.e.*, a slumping motion). Extension occurs when the sitter bends rearward. When the spine is curved inward, as is the case with extreme extension, the spine posture is referred to as lordotic, or the spine is said to exhibit lordosis. Kyphosis is a convex curve of the spine profile, such as occurs in the lumbar area with extreme flexion. The thoracic spine posture is normally kyphotic. In this report, lumbar lordosis refers to the maximum displacement of the back profile from a reference line drawn tangent to the back profile in the buttock and thorax areas (see Reed *et al.* 1995 for more detail).

Spine flexion or extension is accompanied by deformation of the flexible disks between the vertebrae. Each intervertebral disk consists of a gel-like nucleus surrounded by fibrous connective tissue. The intervertebral joint center is not actually a single point, but

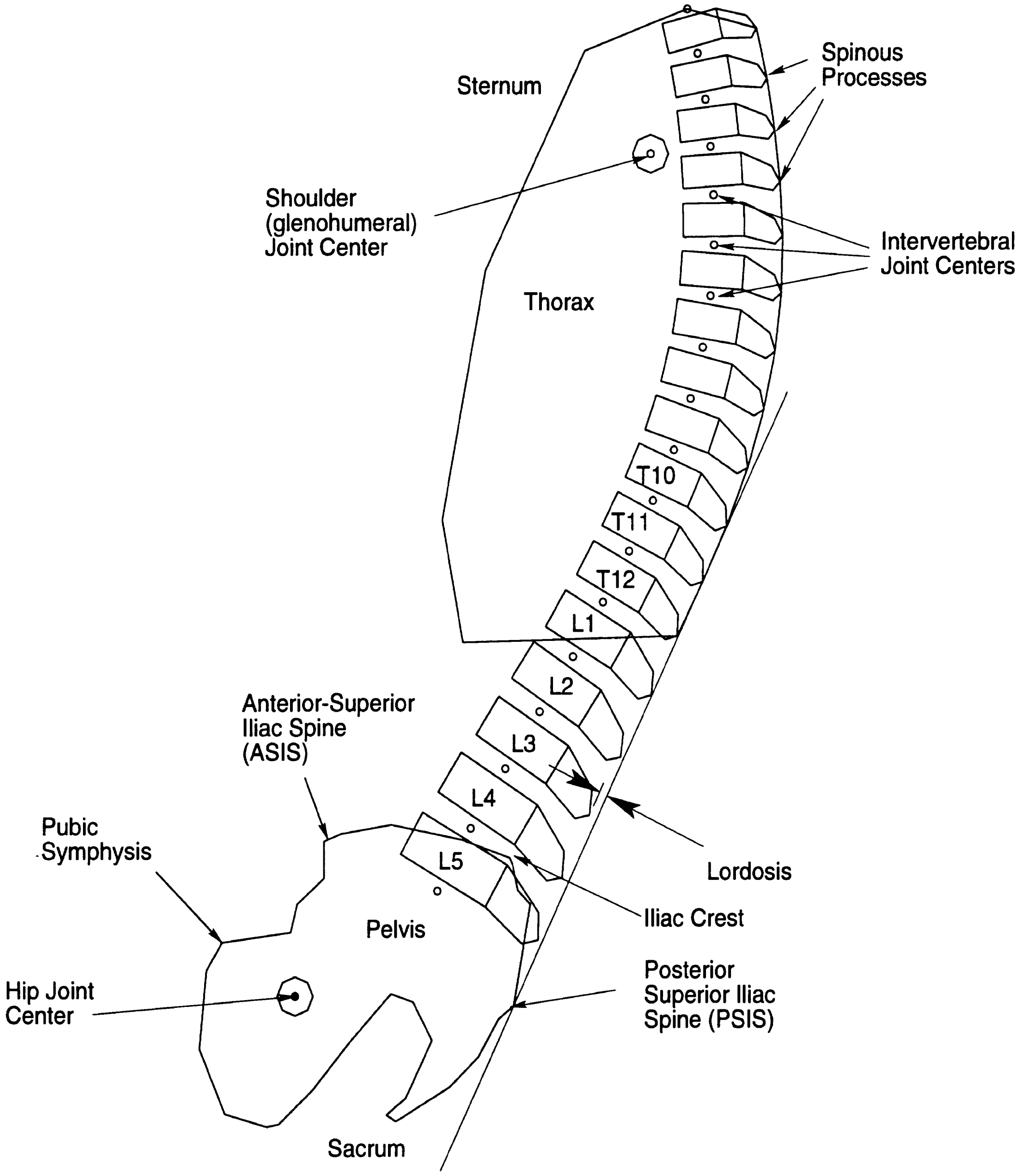

Figure 1. Relevant anatomy, illustrated on a simplified model of the torso skeletal geometry of a midsize male. The orientations of the pelvis, thorax, and lumbar spine are representative of the average posture obtained with a 25-mm lumbar support prominence. Preferred postures with other lumbar support prominences from 0 to 45 mm differ only slightly.

rather moves somewhat during flexion or extension of the joint. However, for seating analysis, the joint center can be reasonably approximated as a single point near the center of the intervertebral disk.

Torso geometry varies widely across the driving population. Figure 2 shows the typical torso skeletal geometry of females who are 5th percentile in the U.S. population by stature and males who are 95th percentile by stature, based on linear scaling of the model in Figure 1, using the distance from the hip joint center to the T4 spinous process given in Schneider *et al.* (1985) as the scaling criterion. More accurate representations of small-female and large-male anthropometry are available in Schneider *et al.* (1985), but this method gives estimates of the range of torso geometry in the driving population that are sufficiently accurate for lumbar support design.

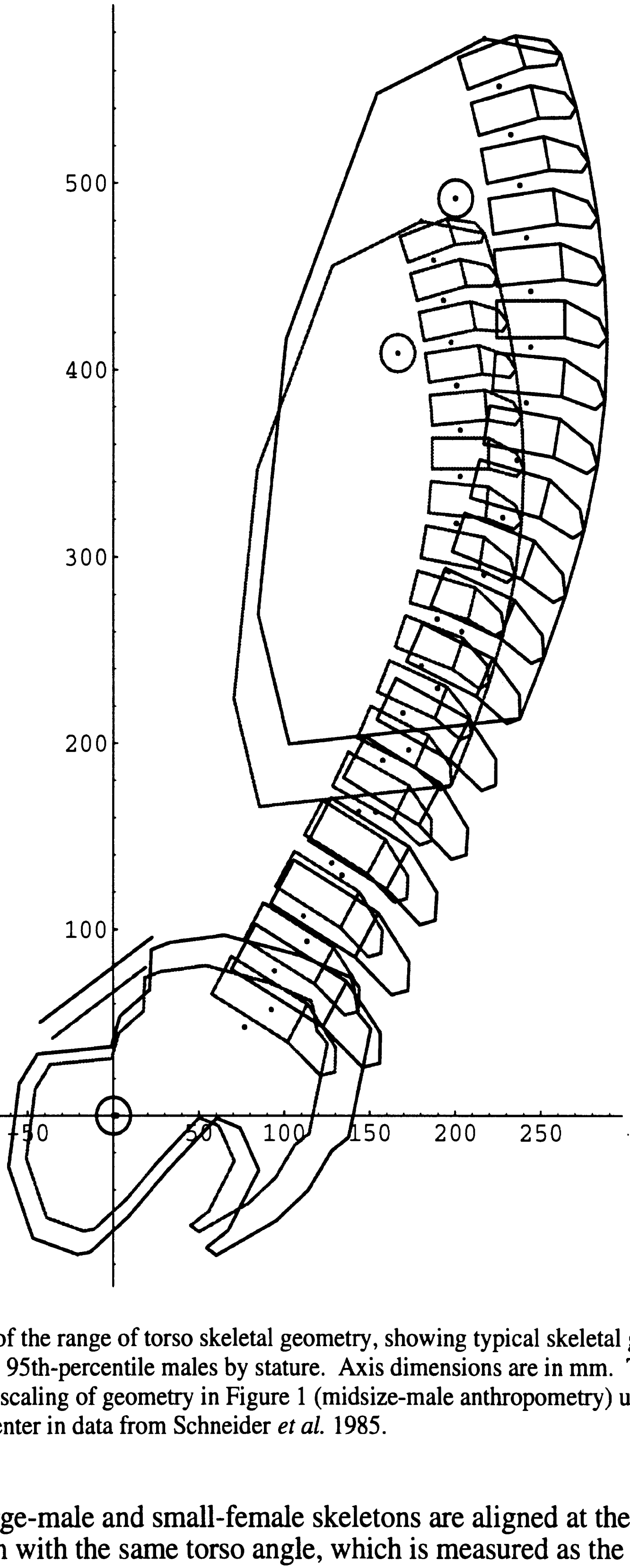

Figure 2. Illustration of the range of torso skeletal geometry, showing typical skeletal geometry for 5th-percentile females and 95th-percentile males by stature. Axis dimensions are in mm. This illustration is based on proportional scaling of geometry in Figure 1 (midsize-male anthropometry) using the distance from T4 to hip joint center in data from Schneider *et al.* 1985.

In Figure 2, the large-male and small-female skeletons are aligned at the hip joint center and they are shown with the same torso angle, which is measured as the angle relative to the vertical of a line from the hip joint center to the shoulder joint. The assumption that sitters of different sizes have comparable hip joint center locations has been shown to be reasonable for typical auto seats, and Reed *et al.* (1995) found similar torso angles for sitters from different stature groups.

Robbins (1986), using data from Schneider *et al.* (1985) and Robbins *et al.* (1985a, 1985b), found merging sitter anthropometry at the hip joint centers to be a suitably accurate approach, based on seated anthropometry of drivers. Manary *et al.* (1994) did not find significant differences among stature groups in hip joint center locations for three typical auto seats. In Reed *et al.* (1995), the study on which these design recommendations are based, the hip joint centers of taller sitters were slightly further forward on the seat than those of shorter sitters. However, the seat used in that study was not representative of typical auto seats. The lumbar support was thinly padded so that sitters with different upper body masses would experience approximately the same support contour. This effectively merged the sitters' postures on the back contour line so that sitters with larger pelves had hip joint center locations that were further forward than those with smaller pelvic bones. In production auto seats, relatively soft padding is used in the lumbar area to reduce pressure peaks and to give a more even distribution of support force. Heavier subjects deflect the padding more than lighter subjects, so that the lower part of the back contour line is further rearward. This variable deflection brings the hip joint center positions of different stature groups into approximately the same position.

In addition to being comparable for different anthropometric groups, mean hip joint center locations are also reasonably approximated by the seat H-point measured using the SAE J826 manikin and procedure. Manary *et al.* (1994) found that the mean hip joint center location was about 13 mm forward of and about 8 mm above the H-point of the seat measured using typical auto seats. In Reed *et al.* (1995), the mean hip joint center locations were further forward relative to the H-point because of the effects of minimal padding on the backrest, but the average vertical offset was comparable (7 mm). For lumbar support design, the vertical positioning of the sitter's skeleton is the most important anthropometric consideration, because that information is used to locate the lumbar support appropriately. The fore-aft positioning of sitters with different anthropometry is determined by the seatback foam stiffness and depth. These effects are considered in more detail below.

In addition to the location of skeletal landmarks, body and seat contours are useful in describing seated posture. Figure 3 illustrates four side-view curves of interest when discussing a sitter's posture and its relationship to the seat. The curve linking the joint centers is the best indicator of the sitter's spine posture, but is difficult to determine without radiographic analysis. The spine profile, formed by the curve joining the spinous process surface landmarks, is the curve most frequently described as the "back profile." However, the most rearward projection of the sitter's body in the low-back area is often the soft tissue over the muscles adjacent to the spine. This is especially true for substantially lordotic postures, such as many people choose when standing. However, a firm support in the low-back area can compress the soft tissue so that the spine profile and the sitter's back profile are coincident. The seatback profile is the same as the more rearward of the sitter's spine or back profile, but only in the areas where there is contact between the sitter and seat. The lumbar support design recommendations in this report assume that the spine and back contours are approximately the same, and attempt to make the seatback profile coincident with the sitter's back profile throughout the low-back region.

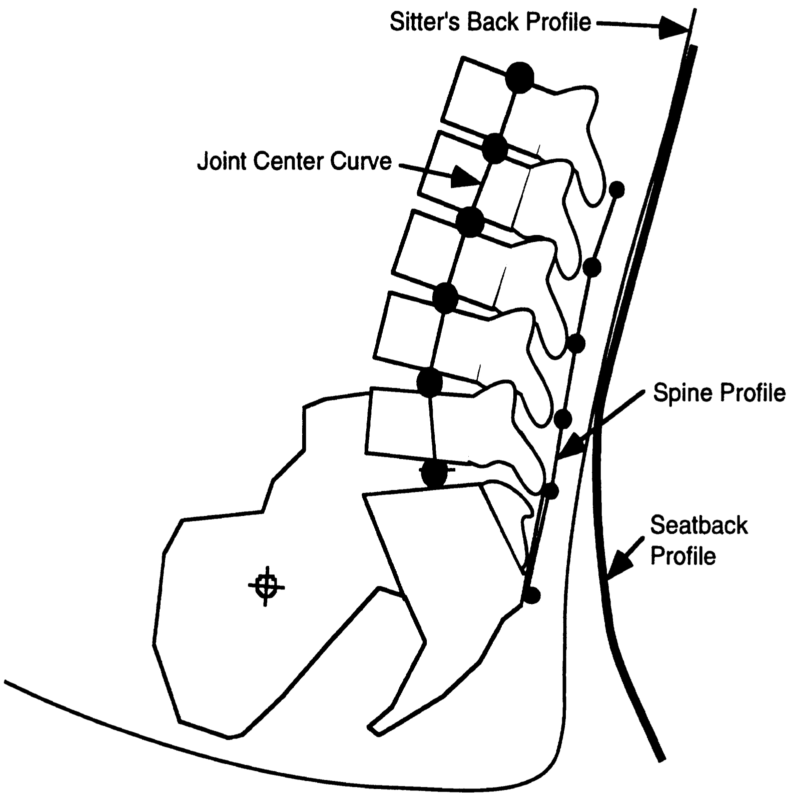

Figure 3. Schematic illustration of several curves that can be used to describe the sitter's back contour and the interaction between the sitter's lower back and the seat.

2.2 REVIEW OF THE RECENT FINDINGS

2.2.1 Overview of the Study

Male and female subjects ranging in stature from the 5th percentile of the female U.S. population (Gordon *et al.* 1989) to the 95th percentile of the male U.S. population were studied. A test seat, adjustable to five lumbar support prominences ranging from 0 to 45 mm, was mounted in laboratory vehicle mockup that included a steering wheel, instrument panel, accelerator pedal, and brake pedal positioned to match the interior of a contemporary minivan. The steering wheel and pedals were interfaced with a computerized driving simulator program that displayed an interactive driving scene on a large screen about 10 feet in front of the subjects. Subjects sat in the vehicle mockup and adjusted the seat track, seatback recliner, and steering wheel tilt to comfortable positions. Postures were recorded by digitizing body landmarks on the head, thorax, pelvis, and right leg with a sonic digitizing system.

In the first phase of testing, the postures of 48 subjects were recorded at 10-minute intervals during a one-hour driving simulation. Each subject was tested with 0, 10, and 25 mm of lumbar support. Subjects adjusted the vertical position of the lumbar support prior to each trial. In the second phase of testing, 32 of the original 48 subjects returned for testing with lumbar support prominences of 0, 25, 35, and 45 mm. A two-minute driving simulation was used during the second phase, since only small posture changes had been observed during the previous one-hour tests. Subjects' preferred postures were recorded during trials in which the vertical position of the lumbar support was fixed, and also after the subjects were allowed to adjust the support over a 120-mm range. Subjects also participated in trials in which their sitting procedure was prescribed, by instructing the subjects to sit in such a way that their lumbar lordosis was maximized.

This study provided considerable quantitative data regarding preferred postures and the effects of lumbar support prominence and vertical adjustability on those postures. In the remainder of this report, the implications of these findings are examined to make specific recommendations for the design of lumbar supports for auto seats.

2.2.2 Summary of Findings

For a full presentation of the results of this study, see Reed *et al.* (1995). In this report, only those findings that directly affect the specification of the seatback contour are discussed. These include:

1. Preferred postures, defined by body segment orientations, differ widely among subjects. In particular, pelvis angle and net spine flexion relative to standing vary considerably.
2. Most seated back contours in preferred postures are nearly flat for about 180 mm above the point of maximum lordosis, even with the large range of posture variability observed.
3. The mean location of the point of maximum lordosis in the lumbar back contour is about 144 mm above the sitter's hip joint centers.
4. The mean preferred lumbar support apex location is about 152 mm above the sitter's hip joint centers.
5. The mean hip joint center location is about 7 mm above the manikin-measured seat H-point for lumbar support conditions for which the H-point can be reliably measured. Adding 7 mm to the values reported above, the location of the maximum prominence of the back contour and the mean preferred lumbar support position are 151 and 159 mm above the seat design H-point, respectively. These values are rounded to 150 mm and 160 mm for purposes of this report.

3.0 RECOMMENDATIONS FOR SEATBACK DESIGN

These recommendations address the design of fixed- and adjustable-contour automobile seats. The primary focus is lumbar support, or the area of the seatback extending from the H-point to about 300 mm above the H-point. In Section 1.2 of Reed *et al.* (1995), the prevailing ideas among ergonomists and seat designers concerning the purpose and proper configuration of lumbar support were discussed. Most lumbar support designs are intended to induce lordotic lumbar spine postures. Such postures have been found to result in lower stresses on the lumbar spine than flatter, more flexed spine postures. However, the findings of the recent study demonstrate that substantially lordotic postures are not common in auto seats, even when a prominent, firm lumbar support is provided. Analysis of leg and pelvis angles suggests that the extended-knee posture required in auto seats effectively prevents lordotic postures for many sitters through the influence of hamstring tension on pelvis orientation.

Longitudinally convex lumbar supports that are intended to mate with a lordotic back curvature can result in uncomfortably high pressures and for inadequate support for sitters with flatter spine postures than the seat designers intended. To avoid these problems, the recommendations in this report are intended to provide support appropriate for preferred sitting postures, rather than for physiologically desirable but unusual and frequently unachievable postures. The recommended seatback contours are similar in some ways to some current vehicle seats, but are quite different from most existing designs in the lower part of the lumbar support and seatback. Proper design of this seatback area is critical if effective support is to be provided to a large proportion of sitters.

Physiological studies of the effects of spine posture on lower-back stresses have demonstrated that reducing the amount of spine flexion in sitting can reduce the amount of stress on the lumbar spine and paraspinal tissues (see Chaffin and Andersson 1991, for a review). When a person sits without low-back support, the spine is restricted from flexing fully only by the action of the back extensor muscles. Since continuous muscle exertion is uncomfortable after a period of time, a person sitting without low-back support usually slouches, flexing the lumbar spine maximally. This posture is referred to as “hanging on the ligaments” because the ligaments connecting the vertebral bodies produce much of the tension that maintains the slumped posture. In addition to stresses in these ligaments, fully slumped postures also produce relatively high levels of intradiscal pressure in the spine.

To alleviate the discomfort caused by highly flexed postures or continuous muscle exertion, most chairs and seats have a padded support in the lower part of the backrest, which can reduce the amount of lumbar spine flexion in comfortable postures if properly designed. The primary effect of a lumbar support is to allow sitters to choose seated postures with less than maximal spine flexion and reduced or minimized back muscle exertion. Without a lumbar support, postures with less than maximal lumbar spine flexion generally require considerable static muscle exertion. When a person is sitting relatively upright, with a torso angle of less than about 20 degrees to the vertical, some back muscle activity is necessary to prevent the thorax from slumping forward, even with a lumbar support. In this situation, the lumbar support can help by preventing the pelvis from rotating rearward under the weight of the upper body, thereby reducing the amount of tension that the back muscles must generate to prevent the spine from flexing further.

For postures with the torso reclined more than 20 degrees relative to the vertical, which is typical of driving postures, back muscle activity is minimal for a wide range of spine flexions when the low-back area is supported. For these postures, lumbar support does not decrease the already minimal back muscle activity, but it still performs the basic role of restricting rearward pelvis rotation and hence prevents the spine from flexing maximally. Since spine flexion increases stress on the spine and paraspinal tissues, the purpose of the lumbar support in reclined postures should be to limit spine flexion to the minimal amount that is comfortable for the sitter.

If the seatback design attempts to restrict spine flexion to a level less than that required by the sitter for comfort, a mismatch occurs between the contours of the lumbar support and the sitter's back. This happens frequently when a seatback is designed for a lordosis approximating the typical standing spine lordosis, because few sitters prefer such postures in auto seats.

A good lumbar support design will meet the following criteria for the desired percentage of the user population:

1. The seatback will contact the sitter fully over the whole lumbar region, *i.e.*, contact extending upward from just below the top of the pelvis.

2. The seat back will provide support for a posture with the minimum spine flexion with which the sitter is comfortable.

3. The seatback will allow the sitter to obtain support over the whole lumbar area for postures with a range of pelvis angles and lumbar curvature, including the minimum-spine-flexion posture.

4. The seatback will allow sitters to sit comfortably for the desired sitting duration.

Contact throughout the lumbar region is important for two reasons. The joint between the lowest lumbar vertebra and the sacrum, L5/S1, generally has the largest range of motion of all of the lumbar joints. Consequently, if the back of the pelvis is not supported, this joint will flex considerably as the back muscles are relaxed. This is a frequent problem in seats with too-prominent lumbar supports, because sitters who prefer flat-spine postures generally have minimal contact with the seat below the apex of the lumbar support and consequently receive inadequate support at the base of the lumbar spine. A large contact area is also desirable because it reduces the pressure levels necessary to produce the required amount of support force.

The firm, prominent support used in the laboratory study produced preferred postures that represent the minimum comfortable spine flexion in driving postures. Although the test seat may not be comfortable for long-term sitting because of an unfavorable pressure distribution and lack of support for sitters with flat spine postures, the postures observed are likely to be the most lordotic postures that the sitters will voluntarily select. A good lumbar support will provide support throughout the lumbar area for these preferred, minimal-flexion postures.

Seat comfort is enhanced by a design that allows movement between different postures. Providing movement in a driver seat is challenging because of the restrictions imposed by the physical task constraints (hand and foot locations) and the need to resist lateral accelerations. However, it is important to provide for movement in the lumbar spine, because that is the area most associated with discomfort in sitting. Even small amounts of movement should improve comfort by reducing or redistributing stresses. A good lumbar support will allow each sitter to sit with relaxed, supported postures that include a range of back curvatures.

The comfort criterion is extremely important. These recommendations are intended to result in seatback designs that are more comfortable, for more people, than those designed using earlier guidelines. The basis for these recommendations, however, is a biomechanical analysis of the support requirements of preferred postures. Although the posture data on which these recommendations are based are probably representative of preferred postures for a wide range of sitters and seats, the suitability of the designs derived from these data must be evaluated using comfort assessments in methodologically rigorous studies. Some procedures for evaluating prototype lumbar support designs are discussed in Section 4.

3.1 FIXED-CONTOUR SEATBACKS

For the purposes of this report, a fixed-contour seat is one that does not contain user-adjustable features that alter the shape of the seatback, such as an adjustable-prominence lumbar support. Since a production seat will be padded and compliant, the contour is not actually fixed because sitters will deflect the surface of the seat in varying amounts. In general, heavier sitters will deflect the lumbar support padding to a greater extent than lighter sitters and experience a different resting contour. The lumbar support design must allow both heavy and light sitters to sit with a range of back contours that encompasses a sizable percentage of user preferences while receiving good support under the guidelines described above. From a design perspective, a single undepressed contour must accommodate the driving population.

In the recently completed study, preferred back contours were measured for a wide range of lumbar support conditions. A primary finding was that relatively large changes in backrest did not produce correspondingly large changes in preferred postures. In particular, changes in preferred posture between a small-prominence lumbar support and a large-prominence support were small. This finding suggests that seat designers have little influence over sitters' preferred lumbar spine postures.

While this may seem to limit the ability of the designers to improve the sitter's comfort, it actually makes the designer's job easier. If sitters' preferred postures change substantially in response to changes in the seatback contour, then each change to the design must be accompanied by a new prediction of seated posture. Lumbar support design recommendations have typically assumed that changes in the seatback contour will result in identical changes in sitters' back contours. However, the recent findings indicate that sitters' preferred postures will change only slightly in response to changes in backrest contour above a minimum level of support. Thus, instead of designing the contour to produce a single, physiologically desirable posture, the designer's challenge is to produce a seatback configuration that provides good support for the range of preferred postures in the driving population.

In Section 3.7 of Reed *et al.* (1995), mean preferred back contours were presented for four stature/gender groups and four lumbar support conditions. Although mean contours are useful for illustrating the average effects of changes in lumbar support contour on posture, the range of preferred back contours is also important for seat design. Figure 4 shows three back contours calculated with data obtained in testing with 32 subjects, along with the midsize-male torso geometry from Figure 1. The dark contour is the average contour obtained in the most prominent lumbar support condition (45 mm). The light contours represent approximately the 10th- and 90th-percentile lordosis for this test condition. The flatter contour (10th percentile) was obtained by averaging the contours of the subjects who sat with 5th- to 15th-percentile lordosis, while the more curved contour (90th percentile) was obtained by averaging the contours of subjects who sat with 85th- to 95th-percentile lordosis. Each contour is averaged over four subjects. These contours are used to illustrate the required range of depressed seatback contours. The contours are listed numerically in Appendix A.

The subject group from which these data were obtained was recruited from four stature/gender groups so that the distribution of stature in the subject pool is more heavily weighted toward the ends of the population stature distribution. However, the correlation between stature and preferred lordosis was modest (r = –0.28), and the estimated effect was small. Consequently, these data are considered to be reasonably representative of the distribution of preferred back contours in the driving population, in spite of the stratified sampling on stature.

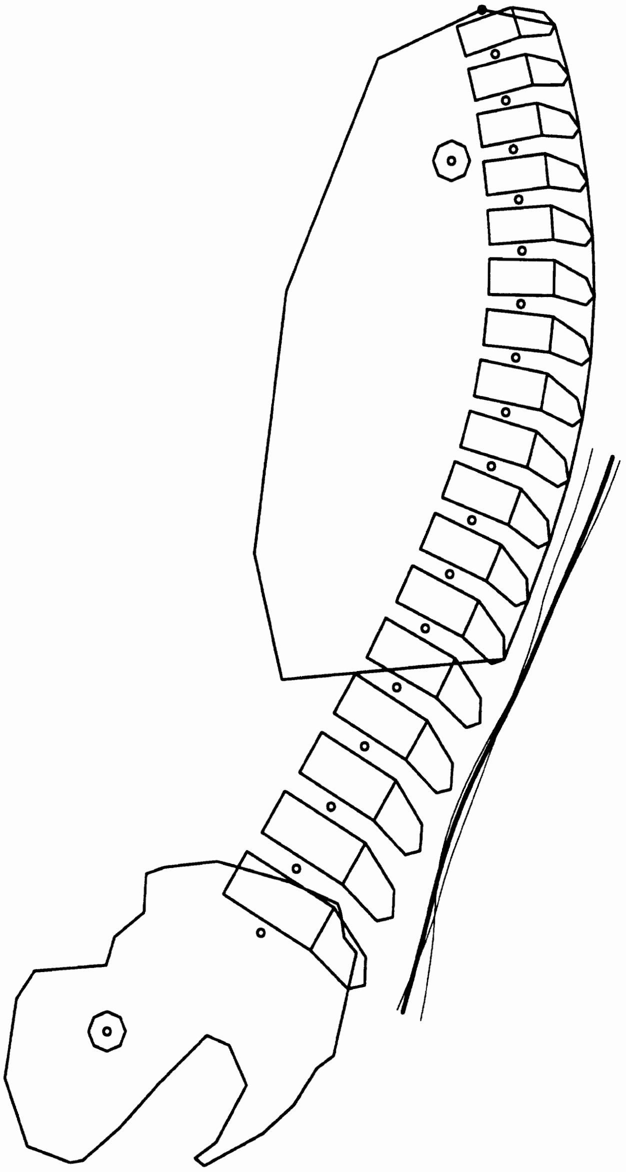

Figure 4. Three back contours in preferred postures along with midsize-male torso geometry. Thick contour is the mean contour for 32 subjects (see Reed *et al.* 1995 for description of calculation procedure). Light contours represent the average contours for subjects with seated lumbar lordosis from the 5th to 15th percentile and 85th to 95th percentile, respectively (four subjects averaged for each contour). Contours are positioned relative to the mean HJC location.

The flatter contour (90th percentile) in Figure 4 lies to the rear of the mean and 10th-percentile contours in the middle-lumbar region. This is due to compression of the lumbar support resulting from the high pressure generated by the interaction of a flat back contour with a convex support. Although the lumbar support used in this study was thinly padded and fairly rigid, some compression did occur. In a production vehicle seat, with considerably thicker padding, a much wider range of compression can be expected to occur at the apex of the lumbar support.

3.1.1 Contour Layout

This section demonstrates how the profile of a fixed-contour seatback can be laid out using preferred seatback contours. The illustration begins with a specified H-point location relative to the seatpan or vehicle space and constructs contours illustrating the desired range of depressed seatback contours. The foam stiffness properties and thickness are then tuned using target pressure values to obtain an undepressed seatback profile. The contours and construction lines are illustrated in Figure 5. The procedure is as follows:

1. Construct a line through the seat design H-point 23 degrees rearward of vertical. This is an initial torso reference line. The mean preferred torso angle in the recent study was 23 degrees, but other information might indicate that some other torso angle is appropriate for a particular application.

2. Construct a line parallel to the torso reference line and 135 mm rearward. This line is a good approximation of the SAE 2-D template back contour in the lumbar area, and also is a good representation of the depressed seat contour produced by a heavy sitter with a 10th-percentile (flat) back contour.

3. Construct perpendiculars to the torso line 115, 160, and 325 mm above the H-point measured along the torso line.

4. Construct an arc with 100-mm radius beginning at the intersection of the initial back contour line and the 115-mm perpendicular and ending at the plane of the foam support structure. For this illustration, the foam support structure is considered to lie 25 mm behind the initial flat back contour line and parallel to the torso reference line.

The lines drawn in these steps are illustrated in Figure 5 along with 50th-percentile-male torso geometry. The 10th-percentile back contour is offset from the seatback for clarity (the measured position lies directly on the initial flat back contour line). The contour is well approximated by a flat depressed seat contour. The skeletal geometry has been located by merging the H-point and hip joint center. In this illustration, the margin between the initial flat back profile and the spinous processes is larger than it usually is with a seated subject. If a sitter with midsize-male skeletal anthropometry had a relatively heavy upper body, he would compress an appropriately designed seatback approximately to the level shown as the initial flat back profile in Figure 5, and sit with his hip joint centers rearward of the location depicted. In contrast, a sitter with similar skeletal geometry and posture but less upper body weight would not compress the seatback as much and would sit with his hip joint centers further forward relative to the design H-point than the heavier sitter. The 135-mm distance between the initial flat back profile and the H-point represents the average distance between the hip joint centers and the back profiles of seated subjects with a wide range of anthropometry.

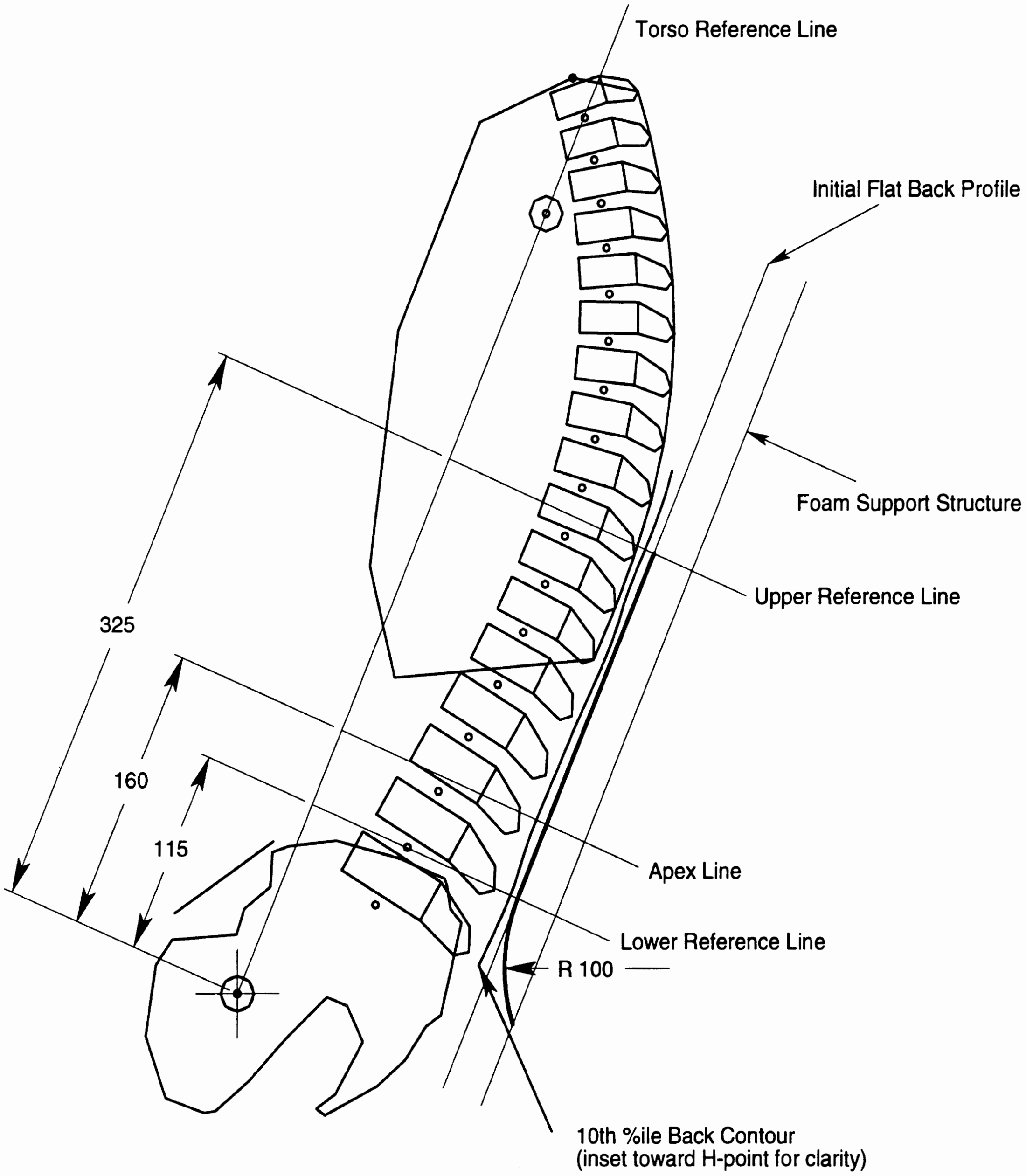

Figure 5. Initial seatback layout. See text for description. Dimensions in mm.

The undepressed seat contour is chosen so that the most prominent part of the undepressed lumbar support is on the apex line (160 mm above the H-point). This is the mean preferred lumbar support apex location. Figure 6 shows a sample undepressed contour line and a flat foam support structure. The undepressed foam thickness at the apex is 58 mm. The flat back profile, which is intended to illustrate the depressed seatback contour produced by a large sitter with a flat-spine posture, represents a 32-mm or 56-percent compression at the apex of the support.

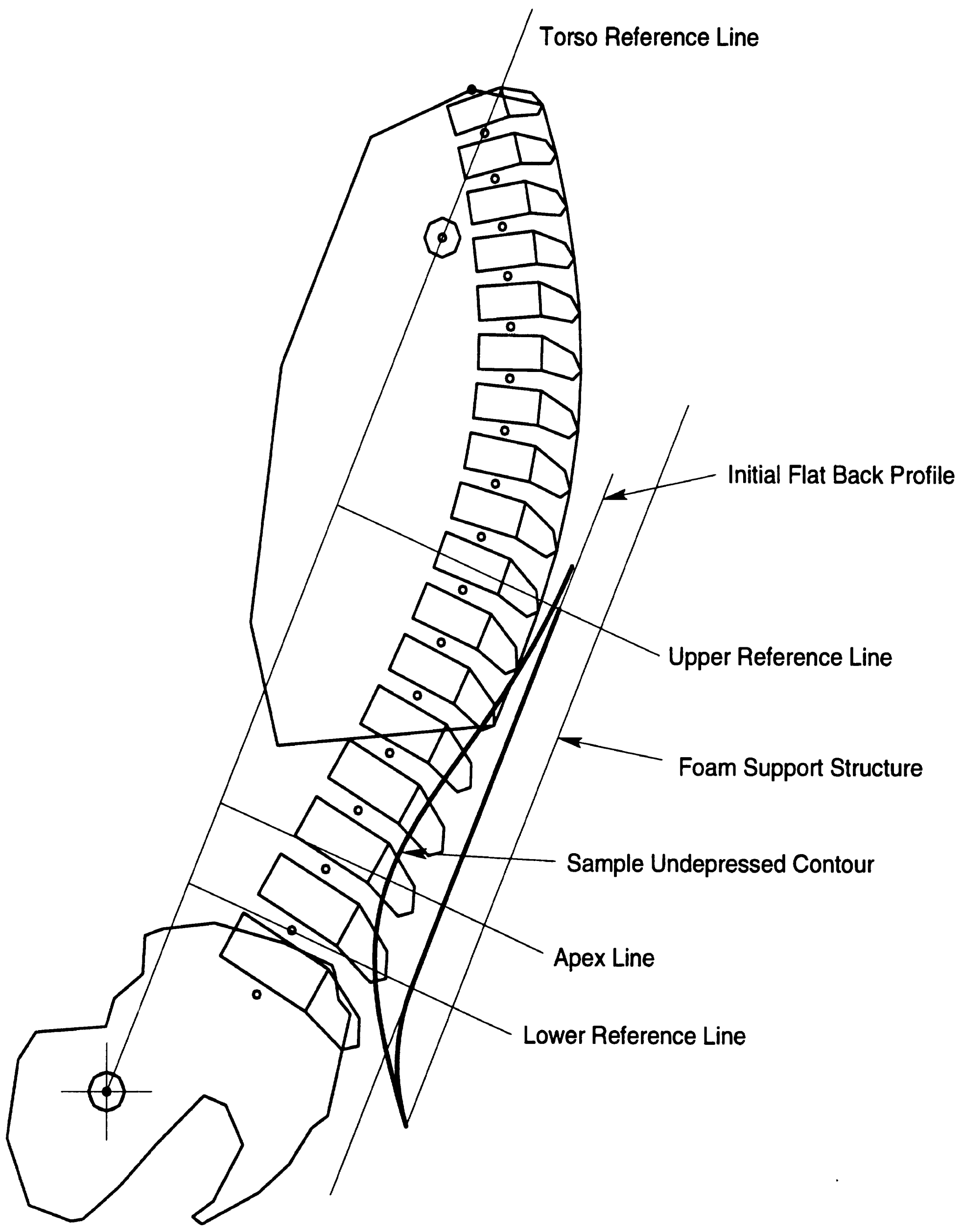

Figure 6. Sample undepressed seatback line, along with a flat foam support structure.

3.1.2 Foam Thickness and Stiffness Calculations

The thickness of the foam (*i.e.,* the prominence of the undepressed contour) and the foam stiffness should be selected based on the desired peak pressures for sitters of various sizes. For this illustration, values of 1 psi for small sitters and 1.5 psi for large sitters will be used, but different pressure levels might be desirable, depending on sitter preferences for padding firmness or surface pressure in the target market segment. The thickness of the foam at the apex and the stiffness of the foam should be tuned to produce the desired range of peak pressure levels while allowing both large and small sitters to obtain support for the range of back contours depicted in Figure 4. The foam pad in the lumbar area is assumed to have linear force-deflection characteristics for this illustration. This is a reasonable assumption for compressions less than about 50 percent of thickness. In this discussion, the foam stiffness is assumed to include any effects of the covering material over the foam, *e.g.*, cloth or leather.

A typical way to measure stiffness is to determine the load required to compress the foam 50 percent using a flat circular indenter with a 100-mm radius (area approx. 314 cm^2). The force required, in Newtons, is referred to as the Indent Load Deflection or ILD. ILD can be converted to psi at 50-percent compression by

$$1\ N_{ILD} = 1\,\frac{N}{0.0314\ m^2} = 0.0318\ kPa = 0.00462\ psi.$$

Thus, a typical ILD of 250 N corresponds to a pressure at 50-percent compression of 1.15 psi. Force-deflection measurements of a seat are dependent on the shape of the indenter, so the average pressure required for a sitter to deflect the lumbar support apex by 50 percent may differ from the pressure measured in the ILD test. However, such a measure of stiffness gives a good starting point for selecting an appropriate foam stiffness and thickness.

In this illustration (Figure 6), the foam thickness at the apex is 58 mm, and the desired compression achieved by large sitters with a peak pressure of 1.5 psi is 53 percent. The relationship between the surface pressure, compression, thickness, and ILD is given by

$$\text{pressure [psi]} = \frac{0.00462\ C\ (2\ ILD)}{T},$$

where C is compression in inches or mm, ILD is the foam stiffness in N from the ILD test procedure, and T is the total foam thickness in the same units as C. The constant converts ILD units to psi. If desired, C/T in the expression can be replaced by the fraction of compression. This equation assumes that compression produced by a seated person is reasonably represented by the ILD test, and that the foam response over the range of interest is linear.

For this example, we can use the target pressure for large sitters to solve for the required foam stiffness. Here,

$$ILD = \frac{(58\ mm)\ (1.5\ psi)}{(0.00462\ psi/N_{ILD})(32\ mm)\ \ (2)} = 294\ N_{ILD}$$

The compression for small sitters at 1 psi is

$$C = \frac{(1\ psi)\ (58\ mm)}{(0.00462\ psi/N_{ILD})\ (2)\ (294\ N_{ILD})} = 21\ mm = 37\%$$

The difference between the small-sitter's and large-sitter's compressions is 32 – 21 = 11 mm.

Although these estimates of foam compression are fairly rough, they are useful to determine if sitters of varying anthropometry with different preferred postures will receive adequate low-back support. Figure 7 shows the illustration from Figure 6 with four additional curves added. The 10th- and 90th-percentile (flat and lordotic) back contours from Figure 4 are shown. The flat contours are located at the apex compression levels calculated above (32 mm and 21 mm for large and small sitters, respectively), but the compressions at the apex for the lordotic contours are smaller, because a lordotic contour results in a larger contact area on the seatback and smaller peak pressures are required to produce the same aggregate support force.

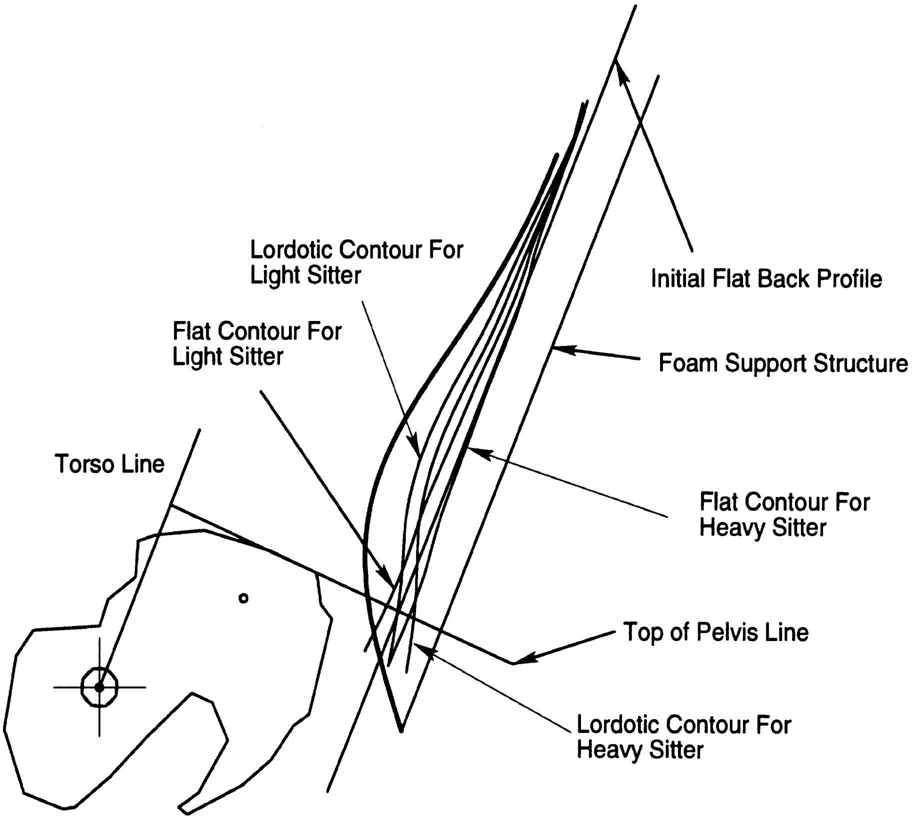

Figure 7. Sample undepressed seatback contour along with lordotic and flat back profiles for heavy and light sitters. Pelvis geometry is approximately that of small females.

Examining the relationship between the back contour location estimates and the undepressed seat surface provides a way of evaluating the support under the guidelines given above. In particular, it is important that the peak pressure location for heavy sitters with lordotic postures remains near the apex, and that the seatback contact for small sitters who choose flat-spine postures extends down to at least the level of the top of the pelvis. The shape of the lower part of the undepressed seatback contour, below the apex of the lumbar support, is determined by these potentially conflicting criteria. The pelvis geometry shown in Figure 7 is taken from the small-female torso geometry illustrated in Figure 2. A line perpendicular to the torso line drawn tangent to the top of the pelvis demonstrates that the sample contours result in contact at the level of the top of the pelvis even for light sitters who deflect the apex of the support 21 mm while sitting with flat back contours. Additionally, the compression pattern when a heavy sitter chooses a lordotic back profile peaks at or near the apex, even though there is considerable compression at the back of pelvis.

The shape of the undepressed seatback profile in Figure 7 is intended to be generally representative of a desirable contour, but the specific contour that is appropriate for a particular seat will be dependent on a number of factors, including the shape of the support structure, the stiffness of the foam padding, and the type of material covering the foam (*e.g.*, fabric or leather). The curve depicted in Figure 7 has a generic shape that can be scaled to different thicknesses depending on these parameters. Appendix B contains a numerical and graphical depiction of these profiles and describes a scaling technique.

There are a number of factors that influence the accuracy of the predicted depressed seat-back contours. Concerns about the validity of ILD as a measure of the force-deflection characteristics have been noted above. Further, seatback angle selection by the sitters influences the relationship between the seatback contour and the vertical, and hence the loading directions, compression, and forces. If a sitter chooses a more upright seatback angle, then the loading patterns on the seatback, and hence the depressed contours, will be different. Similarly, differences in the shape of the underlying support structure will alter the depressed seatback contours.

3.2 ADJUSTABLE-CONTOUR SEATBACKS

3.2.1 Recommendations from Driver Preference Data

In the recent study of driving posture, subjects adjusted the vertical position of the lumbar support to their preferred position. The resulting position data can be used to determine the range of vertical adjustability required to accommodate a desired percentage of the population. The mean preferred lumbar support position for lumbar support prominences of 25, 35, and 45 mm was 152 mm above the sitter's hip joint centers along the J826-manikin-referenced backline (see report for details). Figure 8 shows the distribution of preferred lumbar-support apex locations. The standard deviation was 23 mm. This measurement could not be directly linked to the seat H-point because the H-point machine could not be used reliably with the 35- and 45-mm lumbar supports. For the flat and 25-mm lumbar support prominences, the H-point of the seat was reliably measured and found to lie about 7 mm below the subject's hip joint center location, on average. To estimate the mean preferred lumbar support location, this 7-mm offset was added to the 152-mm value to obtain a mean preferred lumbar support location above the H-point of 159 mm. This has been rounded to 160 mm for design purposes.

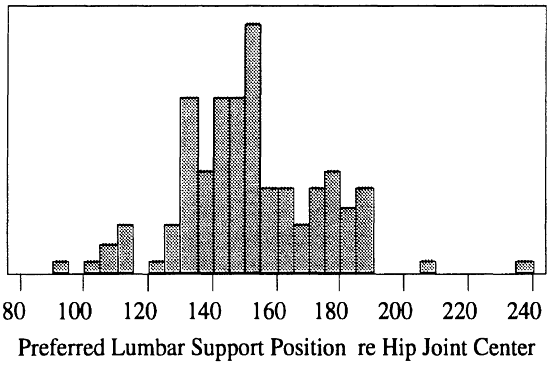

Figure 8. Distribution of preferred lumbar support apex locations relative to the sitter's hip joint center along back line. Mean is 152 mm. The mean hip joint center location is about 7 mm above the H-point.

A Wilks-Shapiro statistical test did not reject the hypothesis that the distribution of preferred lumbar support positions is normal, so a normal approximation was used to estimate population accommodation for candidate designs. Using ± 2 standard deviations (90 percent) as the desired range of accommodation, the apex of the lumbar support should be adjustable to 46 mm above and below the mean preferred position. This value has been rounded to 45 mm, giving a recommended adjustment range for the apex of the lumbar support from 115 to 205 mm above the H-point measured along the manikin back line, a 90-mm range of adjustment.

The most common contour adjustment for seatbacks is an adjustable lumbar support prominence. This is usually achieved by changing the shape of the foam support structure in the lumbar area, either by adjusting a mechanical system or by inflating a pneumatic bladder. The preferred postures observed in the recent study show that about 80 percent of drivers chose postures with between 0 and 25 mm of lordosis. The exceptions were more likely to prefer kyphotic postures than postures with more than 25 mm of lordosis. Figure 9 shows the distribution of preferred back-contour lordosis with a 45-mm lumbar support prominence. The distribution is not normal, with a longer tail toward flat-spine postures. The mean lordosis is 11 mm. Based on these data, a prominence adjustment range of 25 mm is recommended.

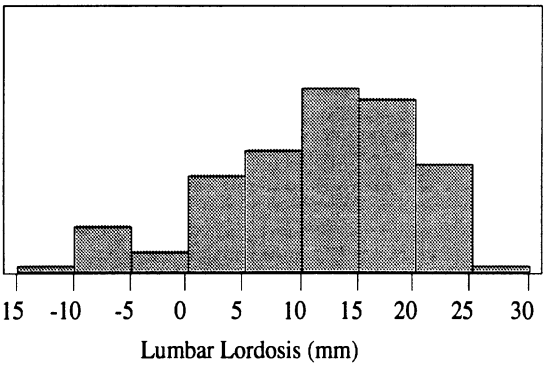

Figure 9. Lumbar lordosis for 32 subjects in preferred postures with a 45-mm lumbar support prominence (mean = 11 mm).

3.2.2 Implementing Adjustable Seatback Contour

An adjustable lumbar support should not be used as a fix for a poorly designed seatback. In particular, an adjustable lumbar support should not be used to make up for a lack of buttock clearance (see Section 4, below). In a seatback with a nearly flat undepressed profile and flat foam support structure, the normal pattern of seatback loading will result in a substantially concave depressed seat contour (kyphotic lumbar spine posture). Many sitters will find an adjustable lumbar support necessary to obtain support for even a flat-spine posture. A seatback for use with an adjustable lumbar support should be designed so that the padding meets the design criteria identified above for fixed-contour seatbacks when the lumbar support is in the middle of its adjustment range.

Figure 10 shows the seatback design from Figure 6 with an adjustable lumbar support. The support is drawn at the top, center, and bottom of its vertical travel. The range of prominence adjustment is 25 mm, centered on the location of the original foam support structure. With the addition of the adjustable support, the support structure has been moved 12.5-mm rearward to accommodate the adjustable mechanism. The height of the support is 100 mm, and the support is curved vertically to produce a smooth vertical pressure gradient. This support is depicted as an ellipse to represent a pneumatic bladder, but a mechanical system could produce the same effect. The undepressed seatback contour should be designed just as a fixed-contour seat would be if the foam support structure was located at the center of the lumbar support adjustment range. The adjustment should provide both greater and lesser prominence relative to the nominal design contour. A good fixed-contour seatback design is a compromise between support appropriate for light sitters who prefer flat-spine postures and heavy sitters who prefer lordotic postures. The goal of providing adjustable prominence should be to provide better support for these sitters who are least accommodated by a fixed-contour seatback.

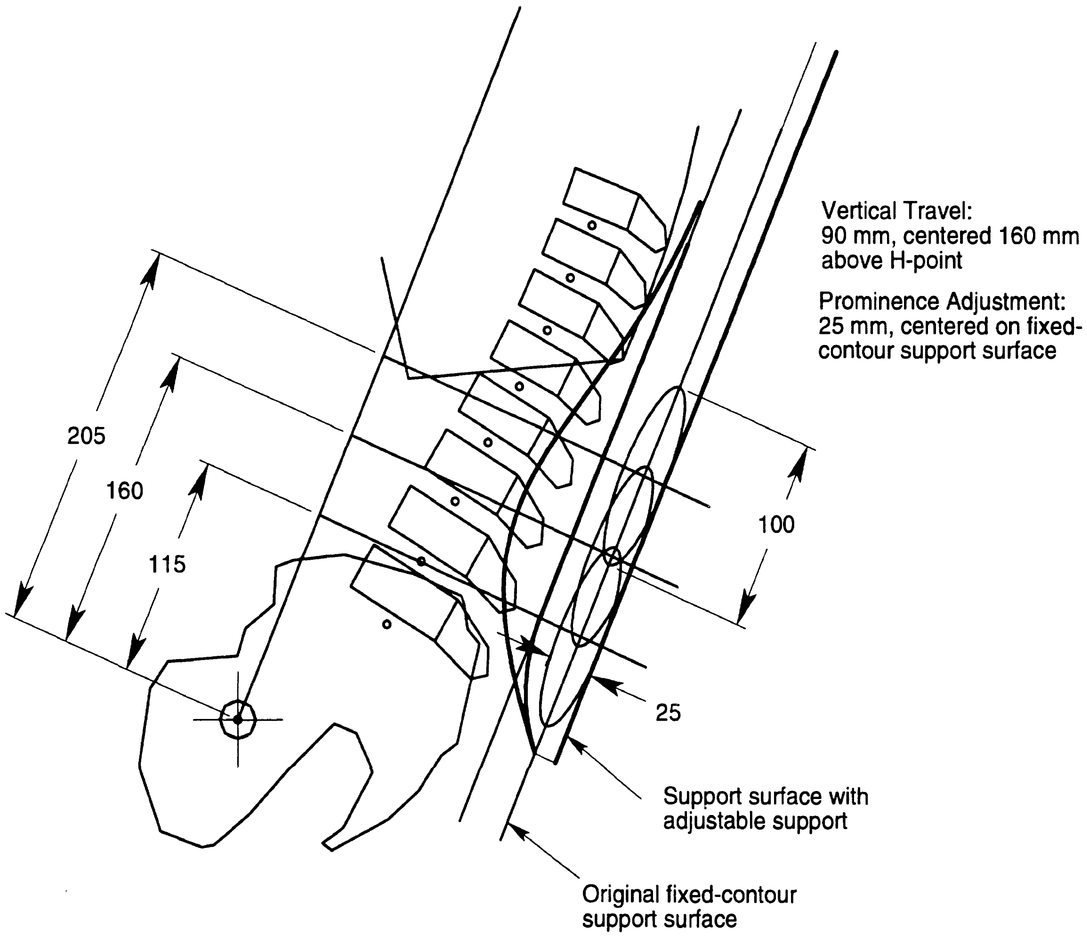

Figure 10. Schematic illustration of adjustable lumbar support. Ellipses indicate the center, uppermost, and lowermost positions. The support surface underlying the adjustable support has been moved rearward by half of the prominence range to allow adjustments with both more and less support prominence than the fixed-contour design.

3.3 ADDITIONAL CONSIDERATIONS IN SEATBACK DESIGN

3.3.1 Buttock Clearance

One important consideration often neglected in auto seat design is buttock clearance. Office chairs are usually designed with an open space below the lumbar support to allow people with a wide range of seated buttock shapes to use the lumbar support appropriately, with a range of pelvis positions. In most auto seats, sitters with large buttocks are forced to sit with their hips further forward on the seat than desirable and consequently cannot use the lumbar support properly. Most sitters cannot shift their pelves rearward on the seat from their normal postures to obtain support for more lordotic postures. To alleviate this problem, the seatback profile should cut sharply away from the sitter below the lumbar support. The bottom end of the arc constructed in Figure 5 represents the lower end of the effective backrest surface. Below this point, which is about 45 mm above the H-point along the torso line, the seatback profile should move directly away from the torso line at least 25 mm behind the flat-spine, depressed-contour line for large sitters (the initial flat back profile in Figure 5) before proceeding downward toward the bite line between the seatback and seatpan. This extra clearance will allow almost all sitters to use the lumbar support properly.

3.3.2 Upper Seatback Contour

Although not addressed in the recent study, the upper seatback design is important for overall comfort and must not interfere with proper use of the lumbar support. In general, seatback pressure above the T10 level, or about 325 mm above the H-point, should be very low or zero (no contact), since pressure in the upper thorax area, *i.e.*, behind the shoulder blades, presses the thorax forward and increases the load on the lumbar spine. Instead, the upper part of the seatback should follow a fairly flat contour above the 325-mm line, approximately parallel to the initial flat back profile line shown in Figure 5.

3.3.3 Lateral Contour

The seatback should have a slightly concave lateral contour, with a smaller radius in the lumbar area than in the upper seatback. The purpose of the lateral contour is to produce higher pressure at either side of the spine than directly over the spine, particularly in the lumbar area. The spinous processes are thinly covered with tissue that is sensitive to high pressure loading. Yet, with a laterally flat or convex contour, the processes usually deflect the seatback more than adjacent body areas and consequently experience higher pressures. A concave lateral contour directs more of the support force onto the back of the pelvis along the width of the posterior iliac crests, as well as onto the large muscle masses on either side of the spine. The lumbar support loads are distributed over a larger area with a consequent decrease in peak pressure, particularly over the sensitive lumbar spinous processes and sacrum.

The appropriate lateral distribution of support force can be obtained by a combination of contours for the undepressed foam and the support surface underlying the foam. Appropriate lateral pressure distribution is particularly important when the seatback includes an adjustable lumbar support. Many supports either increase pressure evenly across the back (band- or strap-based devices) or increase pressure mainly in the center (some single-bladder pneumatic systems). The resulting undesirable pressure distribution may make the adjustable lumbar support uncomfortable for drivers who would otherwise find the system useful. An adjustable lumbar support should increase pressure primarily at the sides of the spine rather than on the centerline of the seatback.

4.0 EVALUATING LUMBAR SUPPORT DESIGNS

Some frequently used techniques for assessing driver interaction with seats can be adapted to verify that a lumbar support design is performing as intended. People who represent the target population by stature and weight should be recruited as test subjects. Also, for some tests, people who are unusual in one or more anthropometric categories should be chosen to study the accommodation of those portions of the population. The test seat should be mounted in a laboratory fixture with a steering wheel and pedals positioned appropriately relative to the seat for the vehicle interior package geometry (*e.g.*, seat height) of interest. Ideally, a driving task will be included to improve the realism of the testing situation.

Testing should cover five areas:

1. Contact Location

It is important that every sitter be in contact with the lumbar support between the T10 and L5 levels. For each subject, the lowest point of contact on the seatback should be measured with the subject in his or her preferred posture. This procedure can be facilitated by proper use of measurement of pressure distribution.

2. Pressure Distribution

There are several requirements for appropriate use of pressure-measurement technology. The pressure transducers should be mounted on extensible mats. Every mat system will change the compliance of the seat, but an extensible mat will result in pressure values that are closer to those that occur without the mat in place. The location of the pressure mat relative to the subject and seat must be accurately recorded for each measurement, so that the pressure measurements can be related to specific locations on the subject's body and seatback.

For a fixed-contour seat, the average peak-pressure location should be at or just above a line 160 mm above the H-point. The pressure should be larger on either side of the spine than directly over the spine. The pressure should extend down to below the top of the pelvis, *i.e.*, to at least the 115-mm level. Seat-surface pressure measured more than 325 mm above the H-point should be minimal. There should be no local pressure peaks outside of the lumbar area (no peaks behind the shoulder blades or against side bolsters).

3. Buttock Clearance

All subjects, even those who are fairly heavy, should be able to sit in the seat without their buttocks contacting the seatback in the area just above the seatpan. If contact is made in that area, the sitters will be unable to use the lumbar support properly. The seatback should be contoured in such a way that all sitters for whom the seat is intended can sit comfortably without contacting the seatback in that area.

4. Use of Adjustments

If an adjustable lumbar support is provided, the adjustment settings preferred by the subjects should be studied to determine if the ranges of adjustment provided are adequate; however, caution should be used in interpreting these results. Some subjects may use a large adjustment range, even though their comfort would not be significantly reduced with a smaller range. It may be more important to evaluate subjective assessments of the range (*e.g.*, not enough range or more than needed) and to evaluate the effects of adjustment range of comfort ratings than to ensure that every subject's preferred location is included.

5. Comfort

Ultimately, the success of every seatback design should be judged by whether it improves comfort over an alternative design. Because most competitive seatback designs are already fairly comfortable, detecting marginal improvements has become more difficult, but highly significant differences in comfort can still be observed. Comfort in seating is best defined as the absence of discomfort, so subjective assessments should focus on measurement of discomfort. Comfort and discomfort are inherently subjective concepts; there can be no "objective" measurement of comfort. However, measurements can be made of correlates of discomfort, such as pressure distributions or levels of back muscle activity, but these should not be construed as measurements of discomfort or comfort.

Proper experimental design is critical in subjective testing. Experiments should be performed using a within-subjects comparison of candidate designs. Subjects should rate (not rank) their discomfort using an open-scale response modality. Typically, a paper-and-pencil questionnaire can be used in which the subject makes a mark on a line connected by the words "No Discomfort" and "Unbearable Discomfort." Test order should be carefully counterbalanced, and repetitions should be conducted to assess the reliability of the results.

5.0 DISCUSSION

The recommendations in this report are similar in some respects to other recommendations in the ergonomic literature (see Reed *et al.* 1994, for a review). In particular, the recommended lumbar support apex location is within 10 mm of the recommendations of several other researchers. The primary difference between these recommendations and previous studies relates to the purpose of the lumbar support, and the resulting recommendations for the prominence of the depressed seatback contour. Lordotic lumbar spine postures have been associated with lower lumbar intradiscal pressure than more flexed postures. Consequently, maintaining the lumbar spine in a posture approximating the standing lordosis is a frequently recommended goal for lumbar support design.

The research on which the current recommendations are based demonstrates that postures with large amounts of lordosis are unusual in preferred driving postures, even when the seat is configured to support such postures. Lumbar supports that are intended for substantially lordotic postures are likely to create undesirable pressure distributions and leave the lower part of the spine unsupported for sitters who choose more typical driving postures.

The goal of lumbar support design is to improve the comfort of the sitter. To that end, stresses that potentially cause discomfort should be reduced to the extent possible. The recommendations in this report attempt to reduce lumbar spine stress by promoting lordosis while providing appropriate support for sitters in their preferred driving postures. A lumbar support that meets the criteria given in this report will provide support for sitters throughout the lumbar area for the preferred back contours of a large percentage of the population.

Another important aspect of these design recommendations is that pelvis mobility for all sitters is encouraged by appropriate construction of the lower part of the lumbar support and provision of adequate buttock clearance. These aspects of the design will allow sitters to obtain support for a wider range of spine postures than is possible with most auto seat designs. Such provisions are common in office chairs, but are infrequently observed with auto seats. The importance of pelvis mobility is increased in auto seats because of the constraints on posture imposed by the driving task.

Use of these guidelines should reduce, but will not eliminate, design iterations. Each candidate design should be carefully tested using subjects who are representative of the target users. There are important interactions between the shape of the undepressed contour, the stiffness of the foam and covering material, and the shape of the foam support structure on the force-deflection properties of the seatback that can not be accounted for with a simple design formula. There is a need for the development of mathematical models of seatback deflection under realistic loading conditions that can be used to further reduce the number of design iterations required to produce a comfortable seat. The relationship between common measures of foam stiffness (*e.g.*, ILD) and the force-deflection properties of the seat should also be examined.

Adjustable lumbar supports can improve the overall comfort of a seat by increasing the percentage of people who are suitably accommodated, and also allow a person to reduce discomfort by changing the seat contour during a sitting session. The adjustment ranges presented in this report are based on posture data and subject preferences in a laboratory study, but larger or smaller adjustment ranges might be justified based on other subjective responses. Adjustable features should not be used as a substitute for appropriate seatback, however. In particular, appropriate buttock clearance should be provided so that sitters can vary their pelvis orientation, and, hence, spine flexion, without having to make an adjustment to the seatback. Ultimately, an automatic control system that can provide changes in backrest contour in response to changes in subject weight distribution might allow a seat to be more comfortable in long-duration sitting than is currently possible with an open-loop lumbar support adjustment system.

5.0 REFERENCES

Chaffin, D. B., and Andersson, G. B. J. (1991). Guidelines for seated work. Chapter 9 in *Occupational Biomechanics, Second Edition,* pp. 335-375. New York: John Wiley and Sons, Inc.

Gordon, C. C., Churchill, T., Clauser, C. E., Bradtmiller, B., McConville, J. T., Tebbetts, I., and Walker, R. A. (1989). *1988 anthropometric survey of U.S. Army personnel: Methods and summary statistics.* Final Report No. NATICK/TR-89/027. Natick, MA: U.S. Army Natick Research, Development and Engineering Center.

Manary, M. A., Schneider, L. W., Flannagan, C. C., and Eby, B. H. (1994). *Evaluation of the SAE J826 3-D manikin measures of driver positioning and posture.* SAE Technical Paper 941048. Warrendale, PA: Society of Automotive Engineers, Inc.

Reed, M.P., Schneider, L.W., and Ricci, L.L. (1994). *Survey of auto seat design recommendations for improved comfort.* Technical Report No. UMTRI-94-6. Ann Arbor, MI: University of Michigan Transportation Research Institute.

Reed, M.P., Schneider, L.W., and Eby, B.A.H. (1995). *The effects of lumbar support prominence and vertical adjustability on driver postures.* Final Report No. UMTRI-95-12. Ann Arbor, MI: University of Michigan Transportation Research Institute.

Robbins, D. H. (1985a). *Anthropometric specifications for mid-sized male dummy, Volume 2.* Final Report No. DOT-HS-806-716. Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Robbins, D. H. (1985b). *Anthropometric specifications for small female and large male dummies, Volume 3.* Final Report No. DOT-HS-806-717. Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Robbins, D. H. (1986). *Study of seatback contours for optimum seat design.* Final Report No. UMTRI-86-39. Ann Arbor, MI: University of Michigan Transportation Research Institute.

Schneider, L. W., Robbins, D. H., Pflüg, M. A., and Snyder, R. G. (1985). *Development of anthropometrically based design specifications for an advanced adult anthropomorphic dummy family, Volume 1.* Final Report No. DOT-HS-806-715. Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

APPENDIX A

Preferred Back Contours

Table A1 lists the coordinates (X-horizontal, Z-vertical) of the three back contours shown in Figure 4 relative to the sitter's hip joint center. The mean contour was obtained by averaging the preferred-posture back contours of 32 subjects as they were sitting in a seat with a 45-mm-prominence lumbar support. See Reed *et al.* 1995 for additional detail with regard to the measurement and calculation procedure. The 90th-percentile contour was obtained by averaging the data from the four subjects whose lumbar lordosis, as measured by the back contour, lay between the 85th and 95th percentile of the 32 subjects tested. Similarly, the 10th-percentile contour was obtained by averaging the contours of the four subjects whose lordosis lay between the 5th and 15th percentiles.

Table A1
Coordinates of Preferred Back Contours in the Sagittal Plane
with Respect to the Hip Joint Center

Mean		90th-Percentile Lordosis		10th-Percentile Lordosis	
X	Z	X	Z	X	Z
160.3	9.7	170.0	5.7	157.3	11.0
163.1	19.4	172.1	15.7	161.4	20.1
166.0	29.0	173.9	25.8	165.6	29.2
168.8	38.7	175.4	35.9	169.7	38.3
171.6	48.4	176.7	46.2	173.6	47.5
174.2	58.1	177.5	56.7	177.0	56.9
176.7	67.9	178.1	67.3	179.9	66.5
179.4	77.6	179.0	77.7	182.7	76.2
182.3	87.2	180.9	87.8	185.8	85.8
185.5	96.7	183.5	97.5	189.4	95.1
188.9	106.1	186.7	107.1	193.1	104.4
192.8	115.3	190.4	116.3	196.8	113.7
197.0	124.4	194.7	125.4	200.6	122.9
201.6	133.4	199.3	134.3	204.3	132.2
206.3	142.2	204.3	143.1	207.9	141.5
211.2	151.0	209.4	151.7	211.7	150.8
216.0	159.8	214.6	160.4	215.6	160.0
220.7	168.7	219.8	169.1	219.6	169.2
225.2	177.7	224.6	177.9	223.6	178.4
229.5	186.7	229.2	186.9	227.3	187.6
233.7	195.8	233.6	195.8	230.7	197.1
237.8	204.9	238.1	204.8	233.7	206.6
241.9	214.1	242.6	213.8	236.3	216.4
246.1	223.2	247.1	222.8	239.5	225.9
250.3	232.2	251.6	231.7	243.0	235.3
254.5	241.3	256.3	240.6	246.7	244.6
258.6	250.4	261.0	249.5	250.3	253.9
262.6	259.6	265.5	258.4	253.8	263.2
266.4	268.9	269.8	267.5	257.0	272.7
270.0	278.2	273.7	276.6	259.9	282.4
273.2	287.7	277.2	286.0	262.4	292.2

APPENDIX B

Prototype Undepressed Contour Curves

The sample undepressed contour presented in this report can be used as a generic template to lay out a prototype design. The contour has three essential characteristics of an undepressed foam contour for use with a relatively flat foam support structure:

1. The apex (most prominent point) lies at the mean preferred lumbar support location. The largest foam compression (and hence highest pressure) should occur at this point.
2. The curve trails off sharply below the apex, but still provides contact at the back of the pelvis for small (lightweight) sitters with flat back profiles, and
3. The curve becomes approximately tangent to the reference line at the T10 level. Above this level, little or no pressure should be observed, indicating minimal foam compression.

Figure B1 shows a family of curves generated from this generic contour. Each curve was generated by scaling the vertical coordinate in the figure. Table B1 contains a listing of the coordinates for the most prominent curve depicted in Figure B1. To obtain a curve from the same family with half the prominence, multiply the Y coordinate by 0.5. To use these curves in seat design, the desired curve should be rotated and translated as appropriate for the particular application. Figure 6 in this report shows a typical curve placement. The upper part of the curve should be tangent to the sitter's thorax in the target posture, while the apex should be located on a line 160 mm above the H-point. The thickness of the foam at the apex should be determined based on the desired foam stiffness and peak lumbar support pressure, as described in Section 3.1.2.

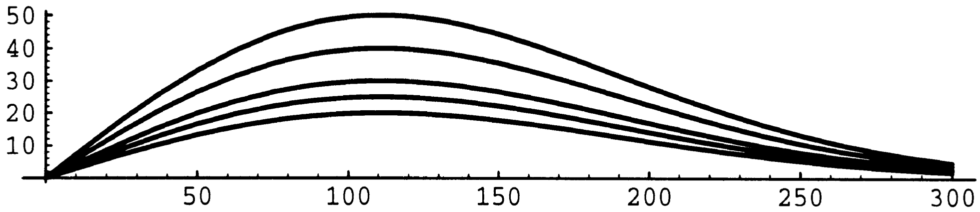

Figure B1. Prototype undepressed seatback contour curves, illustrated on reference axes. Dimensions are in mm.

Table B1
Coordinates of Prototype Undepressed Seatback Contour (mm)

X	Y
0	0.0
10	7.2
20	14.3
30	21.1
40	27.4
50	33.2
60	38.2
70	42.4
80	45.7
90	48.0
100	49.5
110	50.0
120	49.7
130	48.6
140	46.8
150	44.4
160	41.6
170	38.4
180	35.1
190	31.6
200	28.2
210	24.8
220	21.6
230	18.5
240	15.8
250	13.2
260	11.0
270	9.0
280	7.3
290	5.9
300	4.7