ERL-TR-95-006rev.

The Position and Postural Attitudes of Driver Occupants, Seat Position

Herbert M. Reynolds
Douglas Neal
Robert Kerr

June 21, 1996

 Ergonomics Research Laboratory

Preface

This report is the fifth in a series of reports documenting research in the Ergonomics Research Laboratory, Michigan State University sponsored by Delphi Interior & Lighting Systems, General Motors Cooperation (formerly Inland Fisher Guide Division). The experimental protocol has been developed through the cooperation of personnel from Delphi and the Ergonomics Research Laboratory over the course of the past three years. It represents the culmination of several years hard work and creative problem solving efforts to bring objective measures of driver posture and subjective measures of the driver's perceived comfort together into one comprehensive research program.

This research could not have been performed without the combined wisdom and experience of many people from Delphi and General Motors Corporation. In particular, we would like to acknowledge the contributions of Alicia Vertiz, MD, Manager, Human Factors, Delphi Interior & Lighting Systems. Her desire to further the general understanding of driver posture and comfort for the development of automotive seat design tools has led to the current understanding of technology and research tools that are reported in this document. In addition, the people on her staff at Delphi have contributed immensely. We would like to acknowledge the contributions in prior years of Bill Heitzeg and currently Lee Zhang, Ph.D. in their efforts to maintain liaison between Delphi and ERL.

Initially, Don Maertens, GM Mid-Size Car Division, was intimately involved and his cooperation and support by providing the vehicles used in this investigation has been critical to our progress. His involvement has been interrupted by additional activities at General Motors, but his willingness to support research that he sees as important has remained strong.

Lastly, we would like to express our appreciation to the faculty and staff at Michigan State University who have been involved in this research throughout the years of our work. This particularly involves faculty and staff of the Department of Biomechanics, College of Osteopathic Medicine as well as those from other departments and service units within the University that have supported this program in their respective roles.

Table of Contents

List of Figures

List of Tables

The Initial Position and Postural Attitude of Vehicle Operators

Seat Position

I. Introduction

Subjects representative of the mid-sized automobile market segment in the United States drove a four-door 1995 Chevrolet Lumina on three highway trips. We measured their posture, seat position, muscle activity, pressure distribution and comfort under highway driving conditions [1]. Two identical vehicles were instrumented with video cameras to measure anatomical joint center positions (including H-point and D-point in the pelvis) in three-dimensional space, pressure distribution in the cushion and back, and an on-board PC equipped with an A-to-D board that was used to digitize signals from EMG electrodes on the driver's back and all seat position transducers. The seat was a six-way power seat with a power recline and a four-way lumbar support. A technician sat in the back seat operating all measurement equipment and conducting a brief comfort interview at prescribed intervals during the drive. The subjects, obtained from the general population in mid-Michigan, were selected to drive the vehicle without prejudice for halo or marketing effects [2]. This report describes how these subjects used the 12-way power seat in the vehicle to achieve a comfortable or occupant-preferred seat position while operating the vehicle on the highway.

A. Role of the Seat.

A six-way power seat with a power recline theoretically provides the occupant with all adjustments to accommodate personal anthropometric and preference needs to fit the vehicle design package [3,4]. In general, the vertical and horizontal adjustments in the seat primarily accommodate packaging variables of vision and reach. For example, the horizontal (i.e. fore-aft) adjustment accommodates differences in seated leg length (i.e. H-point to Heel point) and the joint angles of the leg between the heel and hip. The front and rear riser height adjustments for seated eye height, however, are very complex because they affect more variables in the seat than seat height. These riser height adjustments can be used to change the angular orientation of the seat cushion which affects functional seat length (i.e. contact length), thigh support, and joint angles. The angular adjustments typically accommodate comfort preferences for joint angles and seat/body contact areas. Equally important to the "fit" variables that these angular adjustments affect is the change in the distribution of occupant body weight in the seat due to changes in body orientation. As a result, riser adjustments can affect pressure distribution in the seat. In summary, the primary six-way power seat adjustments play a large role in the comfort of the occupant.

In addition to the six-way power seat adjustments, the seat back had a two-way power recline and a four-way power lumbar support. In general, the power recline mechanism is a comfort feature that also accommodates large sitting heights and long arms in vehicle packaging. For example, taller individuals can recline the seat to lower their functional sitting eye height. A reclined seat back, however, requires long arms and/or a slouched posture in which the occupant sits in a "shoulders-forward" posture. In an upright seat back, the lumbar support becomes most effective in its role relative to an erect posture in the occupant. The four-way power lumbar support is a comfort adjustment, however, that depends upon proper seat design for full functional use in supporting the occupant's back. Neither the lumbar region nor the pelvis should be pushed into a lordotic posture because the net effect in the seat will be to push the occupant out of the seat. The proper use of the lumbar support is to support, with contact, the curvature of the back in an upright posture. If, for example, the occupant is unable to sit in an upright posture with lumbar extension, the four-way lumbar support will not contribute to the occupant's comfort because pressure on the back will be too great. However, if the seat design accommodates an upright posture, then the four-way support will accommodate differences in the occupant's back curvature in both vertical and horizontal components. In summary, the power seat recline and the four-way lumbar support are most effective in well-designed seats but cannot improve a poorly designed seat.

B. Analysis of Seat Position

Subjects drove the vehicle on three separate occasions. The last drive was a two-hour "comfort drive" and the occupant was able to adjust the seat at his or her discretion. In this dynamic, on-road environment, what position of the seat represents the "desired" or "most comfortable" position for each subject? There are a variety of methods for estimating this position such as using the average of all positions, the greatest length of time in any single position, or some combination of these two approaches. Each method has its advantage but the object of this investigation is to investigate the relationship between comfort and posture. As a result, we will assume that time in position is an important criterion to guide us in our selection of our analytical approach to the occupant's representative seat position. Identifying a procedure to estimate representative seat position for a variety of occupants is an important variable in our analysis since the position of the seat and its comfort features determines in large part the type of seat and its features in the vehicle package for particular market segments.

In many marketing strategies, there is great emphasis on comfort. In recent years, the relationship between seat design and comfort has been emphasized. This emphasis can be seen in the number of vehicles on the road with six-way (or more) power seats. To investigate the association between the seat and occupant comfort, we used three questionnaires: a seat evaluation questionnaire, a post drive comfort questionnaire and verbal questionnaire [7]. The seat evaluation and posture questionnaires were administered at the end of the drive and the seat evaluation questionnaire concluded with an overall assessment of the occupant's perception of the seat. The verbal questions were asked several times during the drive and always at the end when the occupant was asked to summarize his/her level of comfort at the completion of the drive. Results from these questionnaires should correlate with seat position data but the two questionnaires have an experimental artifact that may affect the clarity of this relationship. The questionnaires administered at the end of the drive ask the occupant to either remember their feelings during the drive and integrate these feelings or describe their present feeling of comfort. In contrast, the verbal question asks the occupant to describe feelings at the time on the road when the question is asked. This temporal artifact in data collection will affect the correlation with seat position data since the seat position data are collected while the occupant is driving the vehicle. However, it is hypothesized that if comfort and seat position are associated, then this relationship will be strong enough to be observed despite the differences in methodology. For example, the number of times that the occupant adjusted the seat may be associated with comfort. That is, occupants who move the seat frequently are probably occupants who are uncomfortable. In our experimental protocol, we used a test drive of twenty minutes for the subject to become acquainted with the controls and we ignored the first thirty minutes of the subsequent two drives for the same reason. Thus, we made every effort to remove learning curve effects on these data. Clearly there is a relationship between the occupant's ability to drive the vehicle and comfort. Whether seat position as a generalized parameter in this analysis has an important role in this comfort relationship has not been investigated. In addition, we are concerned in this analysis with the capability of the seat to meet the occupant's desired seat position and the occupant's ability to maintain a comfortable posture in that position.

We investigated the effect of age, sex and stature. These variables are used to determine the market segment for a particular vehicle package design. To determine market effects on desired seat position, differences by age (generation), stature and sex in how different occupants used the seat will be investigated. This analysis divided each of these variables into two categorical strata. For age, the strata were defined by birth year into pre-Baby Boomer (prior to 1946) and Baby Boomers (after 1945). For stature, the strata were defined by average US general population stature as above and below this average. Sex was divided into male and female. In general, these variables also have an association with socio-economic levels in the general population. That is, older and taller individuals often have a higher level of education and associated income. Thus, these results can shed some light on the preferences within a market segment as defined by the mid-sized Chevrolet Lumina.

Since adjustments are built in the seat to accommodate differences in body size, the range of adjustment is usually considered the total range from full rearward to full forward, for example. However, there is also the range of travel used by each subject. This range of travel per subject reflects the amount of travel that the occupant uses to obtain comfort within this vehicle seat/package. These intra-subject changes in seat position are important for comfort investigations because these changes affect joint angle in the driver and weight distribution in the seat. In addition, they may be used to adjust for packaging variables, such as eyellipse location. However, due to the protocol we followed, we feel that these adjustments should not play a large role in the recorded behavior of the driver.

Packaging, as the "fit" of the design interface between occupant and vehicle geometry's, can be investigated by the analysis of "representative" seat positions for the total sample. An extremely important parameter in packaging is the geometric fit between the seat's support of driver position and two operational properties of the vehicle, namely vision and reach. These fit parameters determine, in large part, the ergonomic comfort of the driver in the vehicle. Continuously recording the adjustments made by the driver leads to two different areas of investigation in seat packaging for the dynamic, highway environment. First, it provides the best estimate of "representative" position for the package. Second, it provides an estimate of the overall comfort of the driver in the seat and vehicle package under investigation. As a result, our primary analysis of position and comfort will concentrate on the "free" drive when the driver had complete control over all seat adjustment parameters.

We also conducted a "fixed back" drive in which we controlled the orientation of the seat back regardless of what the driver adjusted in the seat. Each subject drove two short trips of approximately forty-five minutes each in which the seat back was at either 15° or 30° from vertical. These back angles were selected at the extremes of a vehicle package that fits all sizes of individuals in our sample. We were limited by an upright seatback angle that could not be used by a tall individual and conversely by a reclined seatback angle that could not be used by a short individual. Some of the subjects were uncomfortable with the seatback angle and felt that it was a position that they would never personally select, but they were able to operate the vehicle safely without too much discomfort. We were not concerned with comfort during these drives so much as the effect seat back angle had on the subject's posture and seat position.

In summary, seat position and comfort are two complex variables in the total environment. We will show the results in both graphical and numerical manner so that the effects of body size, age and sex can be seen. In addition, limitations in the overall package will be evident from the analysis as well as how drivers use the seat to achieve comfort in highway driving.

II. Methods and Materials

A. Description of Subjects

Forty subjects who met our age, sex and body size criteria volunteered to drive from over 800 subjects in the market sample obtained from R.L.Polk. The participating subjects came from an R.L.Polk database after they voluntarily returned a background questionnaire [1]. The sample was balanced between subjects who were born between 1921 and 1946 (Pre-Baby Boomers) and those born between 1945 and 1970 (Baby Boomers). Body size was controlled by reference to the average stature for males and females in the latest US Army anthropometric survey [9]. Lastly, there were equal numbers of males and females in all categories.

According to the criteria originally given to R.L. Polk, all subjects had bought vehicles in the Upper Middle or Upper Middle Specialty class within three years preceding the beginning of this investigation in 1994. However, the drive subjects reflect a slightly greater range of vehicles. There were 19 subjects (47.5%) who had Upper Middle or Upper Middle Specialty vehicles. The remaining 21 subjects drove vehicles from the upper economy (5%), lower middle (27.5%), traditional large (10%), basic luxury (2.5%), mid-sporty (2.5%), pickup (2.5%), and a minivan (2.5%). A complete description of the distribution of the vehicles has been given previously along with greater description of the subjects between the three stratifying categories [1].

In general, there were no complaints from any subjects regarding the experimental protocol or any aspect of the treatment they were afforded by the ride tech who accompanied them on their drives. The subjects were highly co-operative and very willing to share their feelings about the vehicle and its seat although every effort was made to restrict their comments to how they were feeling rather than how they would design the vehicle or its seat.

B. Description of Seat

1992 Pontiac AM6-W seat frames were installed in each vehicle with 1995 Lumina foam and upholstery. The seat back was modified by the installation of a Schukra 4-way lumbar support. In both the cushion and back upholstery, we installed a zipper at the outer trim so that we could insert pressure mats between the foam and upholstery. In addition to these modifications to the original foam and upholstery, we used an extended seat track in the fore-aft adjustment. Thus, the seat and package are slightly different from those found in the Chevrolet showroom that is available to the customer.

To document the seat and package we used in this investigation, we mapped the centerline in three-dimensional space with a three-dimensional electrogoniometer previously described [1]. After digitizing the centerline of each surface in the vehicle package and seat, data files were converted to IGES format files for AutoCAD (Release 12, 1993) to read. After creating the package and seat drawing file it was manipulated to generate specific seat positions and Oscar [12] was placed in the seat centerline drawing at the design H point location.

First we digitized the three-dimensional contour of the headliner, windshield, and dash along the centerline of the driver as well as the gas-pedal and floor of the car near the gas pedal. Next, we analyzed data from the 1995 Drive study to calculate the preferred steering wheel angle. The steering wheel was placed in the position closest to that determined by averaging the drive data when subjects sat in their modal position, then digitized the steering wheel with a CCM.

The seat including the pan, suspension, lumbar support, and upholstery was measured in design position by digitizing the various surfaces and points. The design position for the extended travel seat track was determined by Jim Bogan at CPE in GMC to be located 40 mm forward of full rear and 20 mm up from the base. After reviewing the drawing it was determined that additional data was needed for the top and bottom surface of the foam and the surface of the fabric when the Velcro type fastener on the cushion to prevent upholstery bridging was employed. Additionally it was decided to measure the seat cushion along both the centerline and the line of thigh contact.

For the new measurements indicated above, the seat was placed in the full down and rearward position and the data was taken as locked plane data streams with the three-dimensional electro-goniometer software [13]. In addition the seat pan was re-measured to verify proper alignment when translating the data to design position. Digitizing the back and bottom surfaces of the foam cushions required that reference points be placed on the seated face of the foam (Foam “A” in Figure 2), and the foam be relocated where the surface in contact with the seat frame and suspension or lumbar support (Foam “B” in Figure 2) was more accessible.

After all seat data had been collected, the seat data were translated 40 mm forward and 20 mm upward. A check of seat-pan alignment verified that the various files were in identical positions.

Seat Co-ordinate to Vehicle Co-ordinate Conversion. The files were originally gathered in the seat co-ordinate system, where the origin is the top of the right-rear seat bolt (Figure 1). The positive x-axis goes from the origin to the right foremost seat bolt; the y-axis runs from the origin to the left seat bolt. We first converted the co-ordinates in the data acquisition co-ordinate system to the vehicle co-ordinate system in AutoCAD so that we were viewing the left side of the seat. Finally, the origin of the seat co-ordinate system or (0,0) point is translated to (3098,237), e.g., the vehicle co-ordinate location of the bolt head as per the co-ordinates in the IL-43686 package drawing. This procedure yields a two-dimensionally correct drawing in the vehicle co-ordinate system. Since the Oscar template does not deal with vehicle y-axis information, there is no need to correct the data for y-axis offset.

Template Placement. With the vehicle interior generated, and the seat placed in the design position, Oscar is placed in the drawing with Oscar’s H-point placed at the H-point machine location per the “Dimension Coordination - CPE, Interior Dimensions (Design VS. Actual)” form completed and submitted by Jim Bogan, 5/25/95 (Figure 2). The design H-point is 3139,452, the CPE measured H-point is 3114,452. The laboratory used the CPE measured H-point location for all design position drawings. Next the back is rotated to the design torso angle, and finally the foot, calf, and thigh are manipulated to place the heel on the floor with the foot slightly depressing the accelerator. Based on the interior package layout drawing IL-43686 [11], the torso angle for Oscar is 26 degrees.

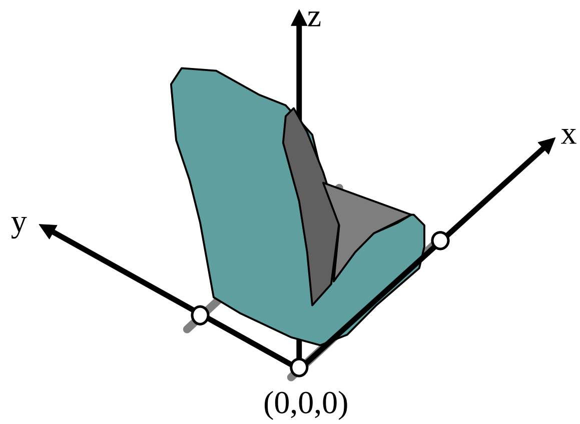

Figure 1. Seat co-ordinate system with origin at right rear bolt.

C. Description of Seat Electronics

In order to record the seat position in the vehicle laboratories, a combination of linear potentiometers and inclinometers were used. The transducers used to sense seat movement consist of a 12 K linear potentiometer attached to one of the drive cables for the seat adjustment gears. The drive cable is installed so that the potentiometer is centered in its operating range. The potentiometer is then electrically installed into the resistance-to-voltage converter circuit described below. The drive cables used were as follows:

Front riser - Cadillac seat memory cable (9” w/ 12K pot {Brown})
Rear riser - Cadillac seat memory cable (15 1/2” w/ 12K pot {Blue})
Fore / Aft - Cadillac seat memory cable (9 1/2” w/ 12K pot {white})

Steering, seat and trunk inclinometers were Midori PMP-S30T transducers W/Midori PV-05 “MR PACK” amplifiers. These inclinometers have a 60° range of measured movement with 0° at the middle of its measured range. The trunk inclinometer was mounted in the electronics enclosure with 0° oriented relative to gravity. The seat inclinometer was mounted on an aluminum bracket designed to hold the inclinometer at 0° when the seat back angle was in the middle of its adjustment range. The steering inclinometer was fastened to a set of plastic wedges to establish 0° on a level mounting platform when the steering column is in the middle position. One wedge rotated the

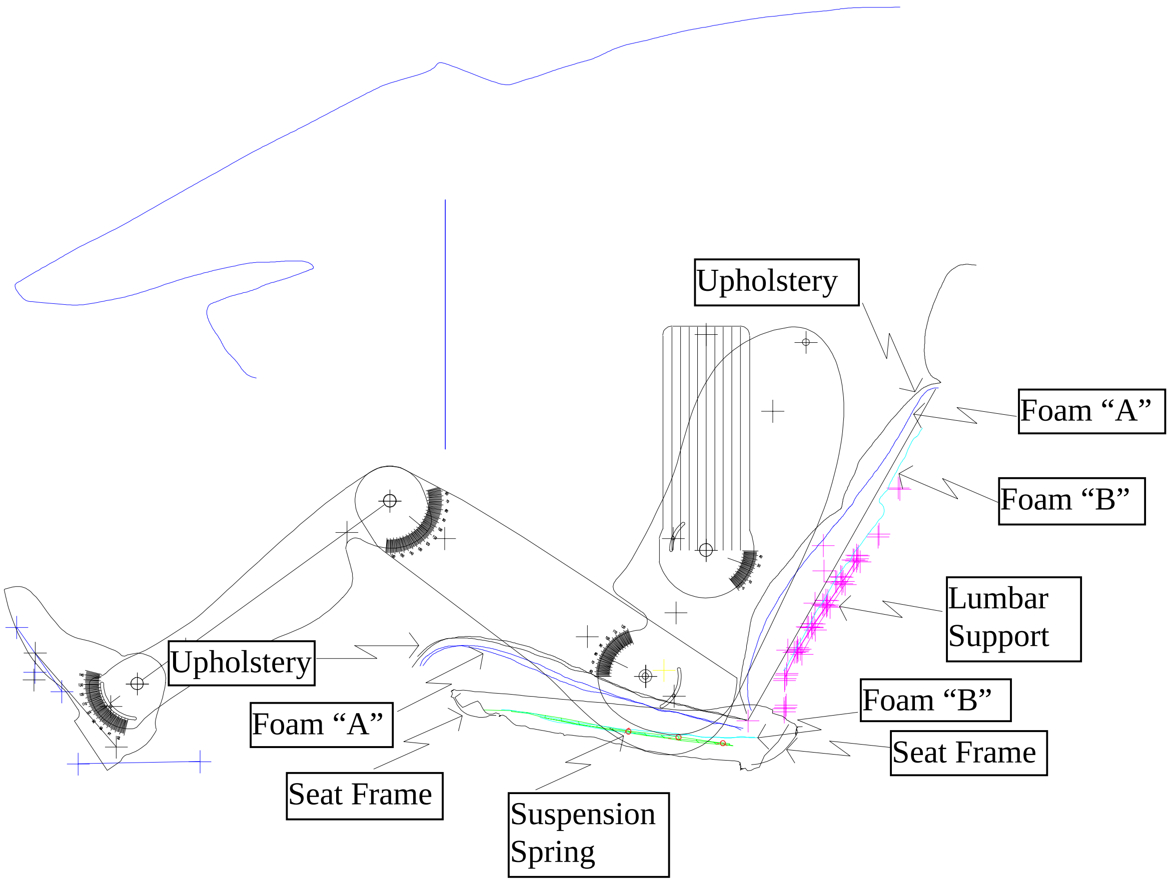

Figure 2. Oscar sitting in AM6-W seat in design position.

inclinometer around the X axis to approximately 0°, and another wedge rotated the inclinometer around the Y axis to 0°.

In the electronics enclosure located in the trunk, a seat position circuit board (Appendix B) was installed to read the position of a car seat based on linear potentiometers in the adjustment mechanisms. In addition, this circuit board had several other important functions. The circuit read the inclination (or tilt) of the steering wheel, seat back, and vehicle based on a signal coming from solid-state inclinometers placed on each device. In addition, the design provided power to the Bio-pak electromyography amplifier [1], as well as a signal path from the amplifier to the A/D card. For the fixed back drives, the circuit provided the ability to automatically adjust the recline angle of the seat back to an angle under the control of the ride tech. As part of the experimental protocol, the circuit board also signaled the computer when the driver of the vehicle made any adjustments to the seat. Lastly, it automatically turned the infrared LED's' on for each set of images taken from the cameras.

The circuit board, developed for this study, consists of the following sub circuits:

(1) Three power supplies: +12 Unreg., +5 Reg., and -5 Reg.;

(2) Five resistance to voltage converters;
(3) A relay driver for the IR. LED's;
(4) A latch & computer interface to signal seat activity;
(5) A series of differential amplifiers to determine vehicle corrected seat back angle;
(6) A comparator-latch-driver circuit to control the back adjustment motor.

Power supplies. The 12-volt supply is simply the reserve battery located in the trunk, with a capacitor filtering out the charging system noise. As the 12 volt circuits are all relatively noise immune, a large degree of regulation was not required. The +5 volt supply is a simple circuit based on the LM78M05 linear voltage regulator. Very little concern need be given to support component selection. Additional details are in the National Semiconductor general purpose linear devices data book [5]. The -5 volt supply is designed around the MAXIM MAX635 -5v switching regulator I.C. External component selection was based on a current requirement of 20 mA. Load calculations for the Maxim MAX635 are fairly critical, as are component values, so the "MAXIM power supply circuits" data book should be consulted for additional details [6].

R-V amplifiers. A resistance-to-voltage amplifier was used to convert the seat position potentiometer information into a signal that could be used by the computers A/D board. The first generation design was based on a single op-amp design which proved to be troublesome since it required a time-consuming and critical calibration process. This design was later modified into a two-stage design. The first stage allowed for balancing the circuit to obtain 0 volts at the lower end of the seat adjustment, this stage maintained a fixed gain for simplicity of tuning. The second stage utilized an adjustable gain to set the output at 10 volts on the upper end of the seat adjustment. This change in circuit design required the addition of two quad op-amp I.C.s, but greatly reduced the time for calibration as well as improving the design's stability.

IR LED Driver. Due to the high current requirements of the IR LED's used, we switch the LED's on only when required for video imaging. The circuit utilizes one section of a Motorola MC1489 Quad Line receiver I.C. to read a signal from the computer's serial port. The output of the line receiver is applied to a switching transistor that drives a 12v relay operating the LED's.

Seat movement signaling. One diode is attached to each of the 12 seat movement signals to form a 12-Input OR Gate. This signal is reduced in level through a resistive voltage divider to drop the signal down to a level compatible with a 7414 Schmitt Trigger IC. When seat activity is initiated, a capacitor is charged through a series resistor and diode. The Schmitt Trigger output instantly goes low. When seat activity is stopped, the diode causes the capacitor to discharge through a variable resistor causing a delay of several seconds. As the capacitor discharges below 1.7 volts, the output of the Schmitt Trigger will go high causing the Q output of a Latch I.C. to go high. The Q output signals an RS-232 Line Driver which signals the computer's serial port that an adjustment has been made. This output stays high until the computer sends a signal to the clear input of the latch.

Inclinometers. Inclinometers were used to measure the rotation around the Y axis of three automotive parameters:

1) steering wheel,
2) vehicle,
3) seat back.

Since the steering wheel position was purely a passive measurement, its signal was passed directly to the A/D board. The fixed back drive angle protocol required that the seat back be fixed relative to the floor pan. To implement the fixed back angle protocol, the vehicle and seat back inclinometer signals were tapped and fed into a back angle comparator.

Fixed back angle comparator. The fixed back angle function is accomplished by utilizing several differential amplifiers to calculate variations of the vehicle and seat from the desired position.

The first stage consists of a differential op-amp used to determine the variation of the vehicle from a horizontal plane, perpendicular to the gravity vector. This is accomplished by tying the output of the vehicle inclinometer to the non-inverting input of the amplifier and applying a fixed voltage of equal value to the inverting input. Any variation in the vehicle inclination will be indicated in the output of this amplifier with the original, calibrated horizontal orientation yielding 0 volts.

The second half of the first stage utilizes an identical differential amplifier to measure the difference between the seat back angle (referenced to vertical) and a computer-generated signal representing the back angle (referenced to the original orientation of the vehicle horizontal plane).

The second stage of the fixed back angle circuit is also a differential amplifier used to compare the variation in the seat back angle to the variation in the vehicles orientation. The output of the first two stages of processing can be represented by the equation

$$V_{out} = (V_{seatback} - V_{lock\ angle}) - (V_{vehicle} - V_{horizontal})$$

where $V_{seatback}$ is the voltage from the seatback inclinometer. $V_{lock\ angle}$ is the computer generated voltage representing the desired seat back angle. $V_{vehicle}$ is the voltage from the vehicle inclinometer. $V_{horizontal}$ is the fixed voltage set to match the vehicle inclinometer output when the vehicle is on a level surface.

The output of the seat angle differential amplifiers is fed into a window comparator whose outputs are logically ANDed with the latch signal from the seat movement sensor to prevent the seat back from being constantly adjusted by random road noise. The two resulting signals (Recline Back, and Elevate Back) are fed to transistor switches driving a set of relays to control back angle.

C. Description of seat position parameters.

For the Fall 1994 Comfort Study, 1992 Pontiac AM6 W-seats were installed in each vehicle laboratory [1]. The AM6 is a six-way adjustable seat with a manual recliner. Several modifications were made to the seat including:

- replace the manual recliner with a power model;
- add a Schukra four-way power lumbar support; and
- replace the standard fore/aft track with an extended travel track.

The seat track has geometrical properties which uniquely affect the interpretation of the seat position data. First, the extended travel track allowed for an additional 31.75 mm of fore-aft adjustment, with approximately 12.7 mm more in the forward direction and 19.05 mm in the aft direction. Second, the track, as measured in the laboratory, is inclined approximately 8.2° from horizontal. This measured inclination of the track, however, differs from seat [10] and package drawings [11] that show 7.502° and 8°, respectively. To compare the seat position data in this report with other similar studies, these geometrical properties of the seat must be considered in the comparison.

In addition to the unique track and seat inclination, the dimensions that are reported for seat position are measured with respect to the relative travel of each physical actuator. For example, the displacement of the front riser jackscrew displacement is measured from its lowest position. The height of the front riser jackscrew in the vehicle axis system, however, changes as a function of seat travel on the 8.2° inclination of the track in the vehicle. Thus, the seat position parameters can only be considered coordinates in a local seat axis system defined relative to the seat track.

Although both seats are essentially identical, slight discrepancies exist in their range of travel (Table 1).

	Car #1 Seat	Car #2 Seat
1. Fore/Aft	203.0 mm	203.0 mm
2. Front Hgt	41.0 mm	42.1 mm
3. Rear Hgt	41.0 mm	42.1 mm
4. Lumbar In/Out	25.0 mm	29.4 mm
5. Lumbar Up/Down	38.1 mm	47.6 mm
6. Back Recline	36°	36°
7. Seatback Inclination	54°	54°

Table 1. Range for seat adjustments by car seat.

Since the Schukra lumbar support uses the deformation of spring steel to provide a continuous change in contour for the low back region, the up/down travel can vary depending upon whether the support is in its maximum or minimum curvature. The travel reported in Table 1 describes the range when the curvature is maximal, that is, the lumbar support is fully out. The travel of the lumbar in/out is simply the measurement of the distance from the most protruding position of the spring steel cage used to define lumbar curvature to the least protruding position.

The seatback can be reclined more than the range of movement in the power recliner (36° total). The absolute position of the seatback can be positioned relative to vertical from 5° to 59°. This extended range of position in the seat back is a combination of seat back position and the relative heights of the front and rear risers. Therefore, certain back angle positions are only attainable if the front and rear risers are adjusted for the additional travel listed above in the 54° total.

Accuracy of Seat Position System. An analysis was performed to determine the accuracy of the seat position system on a per-channel basis. Since the seat position circuit recorded ten samples of the seat's position in less than a one second interval, we assumed that the seat did not move during the course of that sampling interval. Using this assumption, the standard deviation of each channel's 10 samples then represented the instability of that channel. These individual standard deviations were calculated for all the measurement events of 10 subjects and then averaged on a per-channel basis. Due to slight differences in seat position equipment between the two vehicle laboratories, this task was performed for both vehicles. A total of approximately 600 samples was used to determine this per channel accuracy. The results yielded slight discrepancies in accuracy between the two vehicles as shown below (Table 2).

The accuracy reported in Table 2 is based on 1 mm of travel, hence the fore/aft channel in vehicle #1 (±0.001221) which had a 203 mm range of motion would have this accuracy multiplied by 203, or a ±0.248 mm accuracy. A summary of the accuracy of each measurement channel for each of the two vehicle laboratories is shown in Table 3.

Vehicle #	Accuracy of Linear Channels per 1 mm of travel	Accuracy of Angular Channels per 1 deg of Travel
1	±0.001221	±0.007597
2	±0.002926	±0.0084381

Table 2. Accuracy of the Seat Position Circuit per 1 mm of Travel

Slightly lower accuracy for the angular displacement channels is a result of road vibrations that were induced on the inclinometers. Every precaution was taken to fasten the inclinometers as securely as possible, but even slight displacements from road vibrations will result in fluctuations of the output.

	Car 1	Car 2
Seat Fore/Aft	±0.23213	±0.63888
Seat Rear Riser Hgt.	±0.049714	±0.13392
Seat Front Riser Hgt.	±0.064113	±0.12134
Lumbar In/Out	±0.04338	±0.070567
Lumbar Up/Down	±0.03576	±0.101366
Seat Back Angle	±0.520892	±0.557499
Steering Wheel Angle	±0.470256	±0.516266

Table 3. Accuracy of the Seat Position Circuit for each Vehicle Laboratory

D. Analysis Procedures.

The original seat position data contained 10 samples per event, where the number of events depended on two conditions: whether it was the fixed back angle or free drive and how many times the subject adjusted the seat. Each event represented a single point in time during the drive when a measurement was taken. Each set of data was then averaged by throwing out the high and low values and taking the mean of the remaining eight values. The result was a single value for each measurement channel at that particular event. These data were then separated into free, upright and reclined and itemized by subject.

Intra-subject Analysis. For each subject, a number of different parameters were compiled for each of the seven measured channels. These included: the initial and final positions, the change from the final to initial position, the range of adjustment throughout the drive, and the frequency of adjustment. The range was the maximum value that was measured at any point during the drive minus the minimum that was measured. Determining the frequency of adjustment was a somewhat more arduous task. The difficulty arose from separating what was actually an adjustment and what was just a fluctuation caused by the instability of the system, namely in the analog-to-digital conversion. The instabilities were a result of noise in the components of the seat position circuit and were shown as a fluctuation in the least significant bit (LSB). To distinguish between instability and an adjustment, criteria were established based on the standard deviation of each channel. The resulting criteria for adjustment were chosen to be values that were slightly higher than the reported value for the uncertainty of any particular channel. The uncertainty varied for each channel and a summary of the uncertainties can be found in the previous section, “Accuracy of the Seat Position System”. A summary of the criteria for adjustment is listed below (Table 4).

For example, if the Seat Rear Riser Height was moved more than 1.0 mm between any two successive events, then that situation was considered to be an adjustment. A slightly higher criterion for adjustment was used for the Steering Wheel Angle (3.00 deg). This value was chosen because the steering wheel adjustment is notched, such that only five positions are attainable. Therefore, the steering wheel cannot be adjusted in increments that are any smaller than 6.00 deg, so an absolute value of 3.00 degrees is a suitable criterion for adjustment.

Seat Parameter	Criteria for Adjustment
Seat Fore/Aft	>1.0 mm
Seat Rear Riser Height	>1.0 mm
Seat Front Riser Height	>1.0 mm
Lumbar In/Out	>1.0 mm
Lumbar Up/Down	>1.0 mm
Seat Back Angle	>1.0 deg
Steering Wheel Angle	>3.0 deg

Table 4. Criteria to Determine if the Seat has been Adjusted

Inter-subject Analysis. For the inter-subject analysis, the most representative single position for each subject was chosen. By determining this most representative position, each subject could then be easily compared and categorized against the other subjects. The first solution to this problem was to take the statistical mean of each subject's events and call the resulting position the average position for that subject. This solution was ultimately rejected because each event was weighted evenly, despite the fact that individual events are usually of varying lengths of time. In other words, if a subject spent two minutes in one position and 25 minutes in another, the mean for these two events would be calculated and the resulting position would be called the most representative position for that subject. This is clearly incorrect since the subject spent a much larger portion of the drive in the position that had the 25-minute duration. Therefore, the task of choosing the most representative position for each subject had to consider the time duration of each measurement event of that subject.

The second solution to this problem considered all seat positions per unit of time for each subject. The resulting position was called the modal position. Since the modal position for each subject considered the amount of time that each subject spent in that measurement event, it was chosen to be the most representative single position. The modal position was defined as the seat position in which the subject sat for the longest period of time. To determine the modal position, a time record of each measurement event, the data collection log, was examined. The longest duration between changes in seat position in the data collection log was identified. This analysis yields two positions at the beginning and at the end of the modal position period of time. The beginning position of this period of time was chosen as the modal position for that subject.

III. Results

A. Drive subject demographics.

All but one of the forty subjects had excellent health with no injuries in the past six months. The subject who had been injured described a knee injury that had placed some restrictions on her activity, but she was not currently under any medical restrictions for activities such as driving a car for two hours. The majority of the subjects (62.5%) drove primarily on urban or city roads but a few (30%) subjects drove extensively on the highway. The remainder drove under all conditions including rural roads. The most frequent trip length was from 5-20 miles (47.5%) with 27.5% typically driving more than 50 miles per trip. Approximately 40% took a two-hour trip once a week while 32.5% drove this length of time once a month. Ten percent of the sample took a two-hour trip every day.

The majority of the subjects had bucket seats (67.5%) while 25% had split bench and 7.5% had bench seats in their normal driving vehicle. In addition, 35% of the subjects had power seats and 25% of the subjects had adjustable lumbar support in their seat. Three individuals used a seating aid: 1) pillow; 2) beaded mat; 3) foam wedge for additional height.

The forty drive subjects were evenly balanced for sex, age and stature [1]. The average age of the pre-Baby Boomer subjects was 61.8 yrs (M) and 63 yrs (F) and for Baby Boomers, it was 37.8 yrs (M) and 34.8 yrs (F). Stature was 1741 mm (M) and 1624 mm (F) for the Baby Boomers and 1756 mm (M) and 1628 mm (F) for the pre-Baby Boomers. A complete anthropometric description is available in ERL-TR-95-002 [2].

B. The Modal Position: Free Drive

The modal position is the seat position in which the occupant sat for the longest period of time. Data were collected according to collection protocol described in ERL-TR-95-001. This protocol, in general, followed a sequence that collected data at 0, 30, 90 and 120 minutes during the drive unless the occupant moved the seat after the first thirty minutes of the drive. If the occupant moved the seat, the ride tech collected all data and administered the verbal questionnaire. Drive time was defined by a clock in the on-board computer and as data were collected. When the file was saved, the time was written to a log file maintained on each computer in each vehicle.

When examining the files that were saved, it was observed that some files were saved for the seat position data that did not record a change in any of the seven seat and vehicle parameters that were measured. The analysis, therefore, had to examine each set of data to determine if there was a change in data channel value. The criteria for change are in Table 4.

In addition to recognizing whether a change had occurred, it was also important to determine an amount of time for the occupant to make adjustments to seat position. The data collection software was programmed to write a file after 15 seconds of no seat parameter activity. This time between saving files proved to be too short. In examining the files and the time at which they were saved to hard disk, it was discovered that many subjects made sequential changes in seat position before sitting in the seat position for two minutes or more. Thus, we decided that if two or more files were saved sequentially with less than two minutes separating the times in which the seat adjustment was made, the last file in the sequence would describe seat position.

As a result of these data processing procedures, the following variables were calculated to describe the analysis of seat position (Table 5). The number of files was counted for each subject in the Free and Fixed Back Drives (i.e. File #). From each file, the number of seat positions (i.e. SP #) was calculated from the number of sequential files that actually had a change in one or more seating variables (this included adjustments of steering wheel angle). In addition, the number of times that each parameter was adjusted plus the sum of adjustments (i.e. Para #) has been reported. The time from start of drive to the occupant finding his or her modal seat position (i.e. Time To) was measured in minutes and the length of time in that position was also measured in minutes (i.e. Length In). A two-tailed T-Test for samples with equal variances was calculated for each of the variables comparing the results stratified by sex, generation (Baby Boomer vs. Pre Baby Boomer) and stature (Above vs. Below Average Stature). At the .05 level of significance, a difference in the length of time in seat position for generation is statistically significant with BB modal position 9.1 minutes longer than PBB. In addition, the number of seat position changes is also significantly different with PBB making an average of 2.4 more seat adjustments than BB.

In the Free Drive, there were seven seat and vehicle parameters that could be freely adjusted by the driver. These parameters were rear riser height (Rr Riser H.), front riser height (Frt Riser H.), fore-aft length (Fore-Aft), lumbar support height (Lum U/D), lumbar support depth (Lum I/O), back angle and steering wheel angle. According to the experimental protocol, the ride tech was to collect data each time the driver adjusted one of the seat parameters. The software to collect data was written to monitor the length of time following a seat parameter adjustment and then write the data to disk.

Variable	Total	Sex		Generation		Stature	
		Male	Female	BB	PBB	Above	Below
File #	6.4 ± 3.0	6.4 ± 2.7	6.5 ± 3.4	5.8 ± 2.4	7.1 ± 3.5	5.9 ± 2.7	6.9 ± 3.3
SP #	4.4 ± 2.8	4.4 ± 1.9	4.4 ± 3.6	**3.2 ± 1.7**	**5.6 ± 3.3**	4.3 ± 2.8	4.5 ± 2.9
Para #	11.5 ± 9.7	11.2 ± 6.5	11.8 ±12.3	9.4 ± 6.1	13.6 ±12.1	11.8 ±12.6	11.1 ± 6.0
Time To	51.5 ±22.3	50.7 ±18.7	52.4 ±25.0	48.3 ±19.5	54.8 ±24.8	48.9 ±21.6	54.1 ±23.1
Length In	46.4 ±14.6	47.4 ±14.5	45.5 ±15.0	**51.0 ±12.2**	**41.9 ±15.7**	48.4 ±16.6	44.5 ±12.5

Table 5. Description of number of seat positions and length of time (in minutes) in Free Drive modal position (numbers in bold are significantly different at the .05 level).

Table 6 reports the seat position adjustments made by the total sample and strata by sex, generation, and stature. There were no significant differences between any strata. The total number of adjustments during any Free Drive range from 0 to 49 and the average number of adjustments in the total sample was 11.5 (±9.7). There was no difference by sex (M = 11.2 ±6.5, F = 11.8 ±12.3), generation (BB = 9.4 ±6.1, PBB = 13.6 ±12.1) or stature (Above =11.8 ±12.6, Below = 11.1 ±6.0).

Variable	Total	Sex		Generation		Stature	
		Male	Female	BB	PBB	Above	Below
Rr Riser H.	1.2 (±1.5)	1.2 ±1.3	1.1 ±1.8	0.8 ±1.1	1.5 ±1.8	1.5 ±2.0	0.8 ±0.8
Frt Riser H.	1.5 (±2.0)	1.7 ±1.7	1.4 ±2.3	1.9 ±2.6	1.2 ±1.2	1.7 ±2.6	1.4 ±1.3
Fore-Aft	1.9 (±1.9)	1.6 ±1.3	2.2 ±2.4	2.2 ±2.4	1.6 +1.2	2.5 ±2.4	1.4 ±1.0
Lum U/D	1.4 (±1.5)	1.3 ±1.1	1.4 ±1.8	1.4 ±1.7	1.3 ±1.3	1.2 ±1.7	1.6 ±1.1
Lum I/O	1.5 (±2.0)	1.2 ±0.9	1.8 ±2.6	1.7 ±2.5	1.3 ±1.3	1.1 ±1.4	1.9 ±2.4
Back Angle	1.7 (±1.9)	1.5 ±1.6	1.9 ±2.1	2.2 ±2.3	1.2 ±1.2	1.8 ±2.3	1.6 ±1.4
S W Angle	2.4 (±1.6)	2.7 ±1.6	2.0 ±1.6	2.7 ±1.8	2.0 ±1.4	2.2 ±1.8	2.6 ±1.5

Table 6. Number of adjustments in Free Drive for each seat and vehicle parameter for the total sample and by strata in sex, generation and stature.

Given that the number of seat adjustments varied by subject and time during the Free Drive, the modal position has been defined to identify a seat position in which the driver sat for the longest period of time. As reported in Table 5, this period of time varied around 46 minutes (SD = ±14.6). In the modal position, the seat position selected by the total sample is reported in Table 7. H Differ. is calculated by subtracting rear riser height from front riser height.

Variable	Total	Sex		Generation		Stature	
		Male	Female	BB	PBB	Above	Below
Rr Riser H	17.9 ±13.7	16.4 ±13.5	19.4 ±14.1	**13.6 ±11.7**	**22.2 ±14.5**	**11.3 ± 9.4**	**24.5 ±14.4**
Frt Riser H	16.7 ±13.7	19.3 ±13.4	14.0 ±13.8	**12.0 ±12.0**	**21.3 ±14.7**	**11.6 ±11.0**	**21.7 ±14.5**
H Differ.	-1.2 ±14.5	3.0 ±11.8	-5.4 ±16.0	-1.6 ±12.9	-0.9 ±16.4	0.3 ±14.2)	- 2.8 ±15.1
Fore-Aft	34.7 ±40.8	**19.4 ±26.5**	**49.9 ±47.2**	35.1 ±41.8	34.3 ±40.9	**12.7 ±24.8**	**56.6 ±42.3**
Lum U/D	14.5 ±13.7	**9.8 ±12.1**	**19.2 ±13.9**	14.1 ±13.4	14.9 ±14.4	17.0 ±14.2	12.1 ±13.1
Lum I/O	15.3 ± 9.8	13.3 ±10.3	17.3 ± 9.1	14.0 ±10.0	16.6 ± 9.7	**12.1 ±11.7**	**18.4 ± 6.3**
Back Angle	18.1 ± 4.4	19.3 ± 3.8	16.9 ± 4.7	19.0 ± 4.0	17.2 ± 4.7	**19.5 ± 4.0**	**16.7 ± 4.4**
SW Angle	-28.3 ± 8.3	-27.9 ± 8.6	-28.6 ± 8.1	-27.5 ± 7.7	-29.0 ± 8.9	-27.2 ± 9.6	-29.4 ± 6.7

Table 7. Average and standard deviation of the seven seat and vehicle parameters in the Free Drive modal position for the total sample and by strata in sex, generation and stature (numbers in bold are significant at the .05 level).

For the seat adjustments reported in Table 7, only steering wheel angle did not have a significant difference attributed to sex, generation or stature. Rear riser and front riser heights differed significantly by generation and stature. Fore-aft location of the seat differed significantly by sex and stature. The up-down position of the lumbar support differed significantly between the sexes whereas the in-out position of the lumbar support differed significantly by stature group. Back angle also differed significantly by stature group. These differences have been incorporated in the histograms that illustrate the distribution of choices in seat position for the drive subjects in the free drive.

The distribution of subjects in these modal positions was plotted in histograms. The frequency of the front riser, rear riser and fore-aft modal positions was computed for groups defined by equally spaced categories (Figure 3). Once the modal position was established for every subject, these data were then categorized. Each of the individual seat position channels were divided into 5 zones. These zones were equally spaced divisions whose size varied depending on the total range of travel of that particular channel. For example, the Fore/Aft channel had a total range of travel of 203.00 mm. When this range is divided into 5 equal zones, each zone is 40.6 mm wide. The zones for the Fore/Aft channel are shown graphically below.

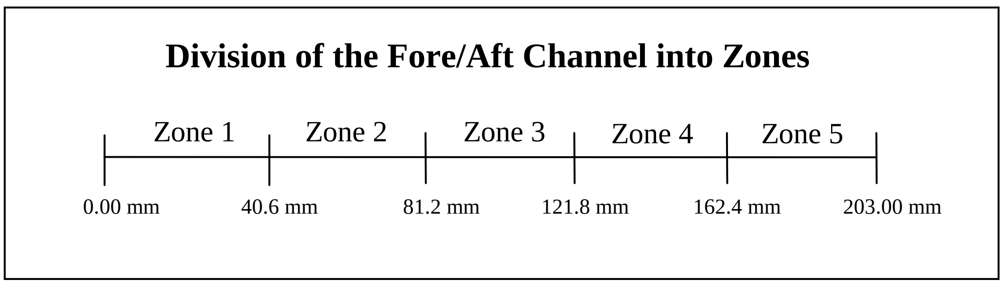

Figure 3. Division of fore-aft travel by equally spaced zones to illustrate distribution of subjects in fore-aft travel.

Once the data are separated into distinct zones, it is possible to determine what percentage of the sample population positioned the seat in each zone. This process was repeated in a similar manner for each of the measurement channels and the results were then plotted in a bar graph form.

The frequency of rear riser modal positions was calculated for divisions of the riser travel of 8.42 mm. There were five divisions and the results for the total sample are reported in Figure 4. The zero position was at the lowest position, closest to the floor and the maximum position was 42.1 mm above zero. The rear riser determines, essentially, the height of the seat above the floor. The stacked bars in Figure 2 report the relative frequencies of the subjects in the below and above stature groups. The distribution shows that the below stature typically used the highest range of rear riser height as opposed to the lower range being used by the above average stature group.

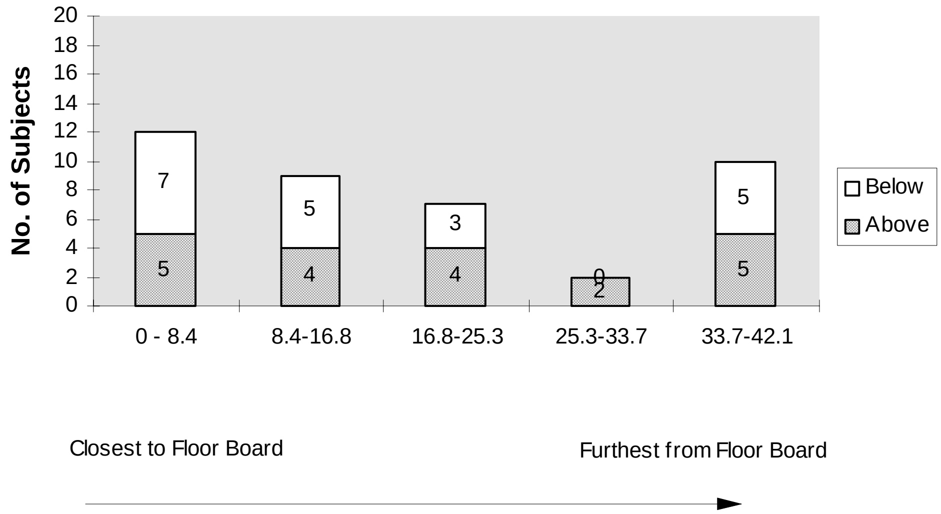

Figure 4. Frequency of rear riser height modal positions in Free Drive.

The front riser height distribution shown in Figure 5 is divided into the same five divisions used for rear riser heights. The maximum front riser height described in Table 1 is 42.1mm, and that is the highest position of the seat from the vehicle floorboard. Although the front riser can be adjusted simultaneously with the rear riser, each riser can also be adjusted independently to change the pitch of the seat cushion. As a result, the distribution of front and rear riser heights is slightly different.

Since there is a statistically significant difference at the .05 level (Table 7) in the use of the front riser height by stature group, Figure 5 shows the distributions of front riser heights for the above average stature group and the below average stature group. The above stature group tends to use the front riser in its lower positions. The below average height group, however, has a bimodal distribution. This bimodal use of the front riser is attributed to the use of the front riser to provide thigh support and change the effective contact length of the seat cushion.

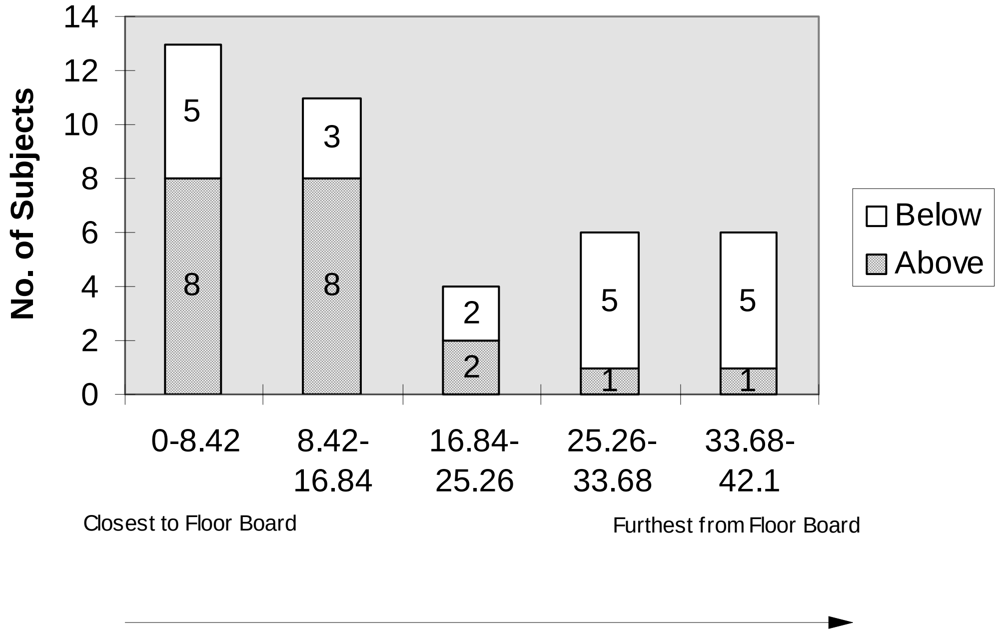

Figure 5. Frequency of front riser height modal positions in Free Drive.

Height difference, reported in Table 7 as H Diff., is determined by subtracting the rear from the front riser heights. In this analysis, zero in Height difference means that front riser height equals rear riser height. Since there is approximately 40 mm travel in front riser height (Table 1), the total range described in Figure 4 is 80 mm, from -40 mm to +40 mm. Unlike the other histograms, height difference is divided into ten categories with each stratum representing an 8 mm range. This height difference reflects the amount of thigh support preferred by the occupant. That is, if the front riser is raised higher than the rear riser, this difference suggests that the front edge of the cushion is raised into the thigh.

Although there is no statistically significant difference at the .05 level (Table 7) in H Difference between males and females, the effect of sex on the relative position of the front to rear riser height is greatest among the three strata that describe sex, generation and stature. The total distribution in Figure 6 is approximately normal. There are slight differences in how males and females use the pitch of the seat cushion. Males tend to raise the front of the cushion whereas females tend to lower the front of the cushion.

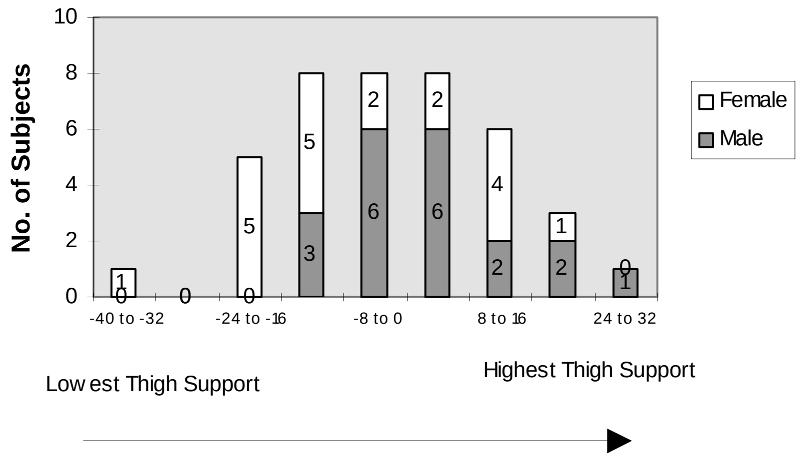

Figure 6. Frequency of riser height difference in modal positions of free drive.

The frequency of locations of the seat in the fore-aft direction is divided into five categories (Figure 7). The total travel is approximately 203 mm, thus, the divisions represent 40.6 mm travel. The results are skewed to the front of the seat, and the zero position is at full rear position of the seat with most above average drivers maximizing the rearward position of the seat. The below average drivers use the more aft positions, but no subjects took the seat to its closest position to the accelerator.

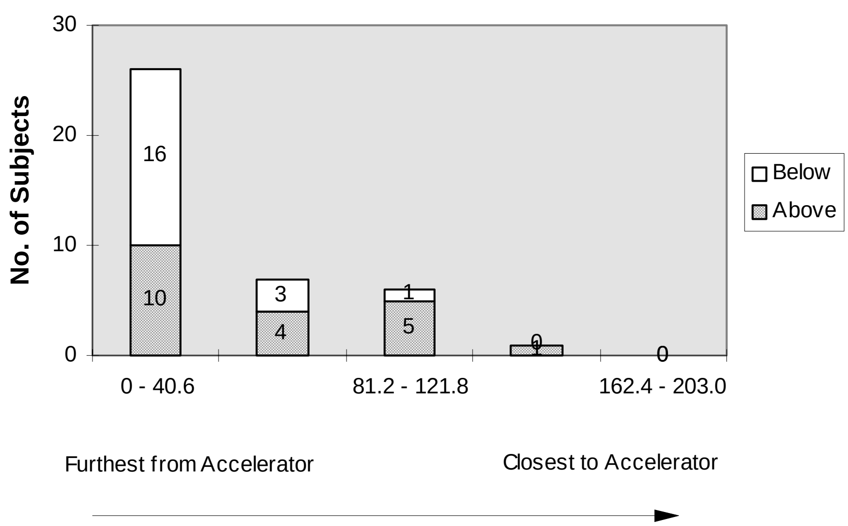

Figure 7. Frequency of the fore-aft seat modal position in the free drive.

The lumbar positions in the up-down and in-out directions are depicted in Figures 8 and 9 respectively. In these histograms, subjects who did not use the in/out travel of the lumbar support were considered not to be using the lumbar support. Thus, nine subjects were excluded from these histograms. The zero position in the up-down direction is at the lowest position and the zero position in the in-out direction is at its most rearward position.

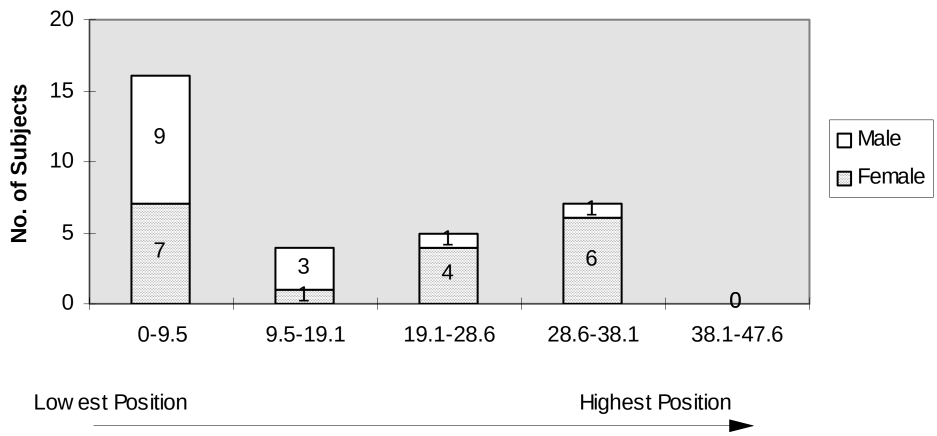

Figure 8. Frequency of lumbar up-down modal positions in free drive (categories in mm).

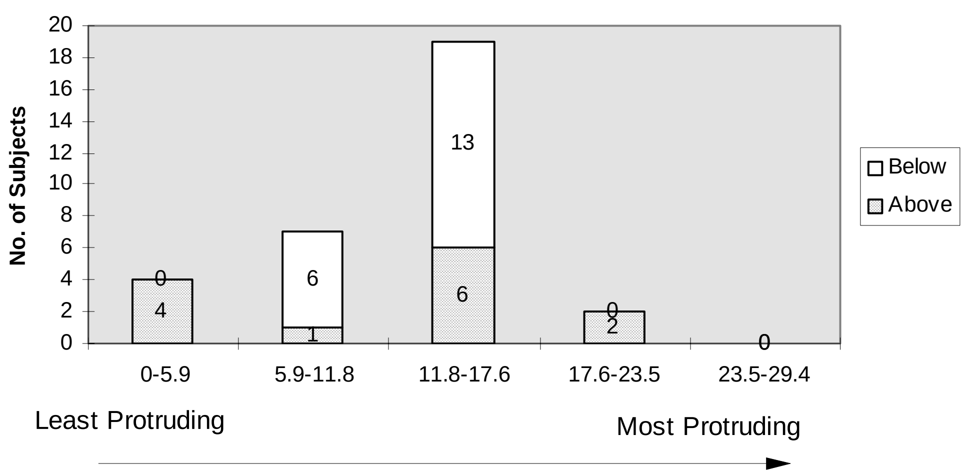

Figure 9. Frequency of lumbar in-out modal positions in the free drive (categories in mm).

The range of seat positions provides an estimate of how much each occupant uses adjustment travel. The preceding data have presented the total amount of travel needed by the population, but the individual occupant does not use the entire range of available travel. As a result, the range of travel in each seat adjustment parameter was calculated from the minimum and maximum position selected by each occupant. The summary statistics on these data are presented in Table 8.

Variable	Total	Sex		Generation		Stature	
		Male	Female	BB	PBB	Above	Below
Rr Riser Hgt	5.7 ± 8.2	5.9 ± 7.8	5.4 ± 8.8	6.1 ± 9.4	5.2 ± 7.0	6.0 ± 8.5	5.3 ± 8.1
Frt Riser Hgt	7.1 ± 9.5	8.1 ± 9.0	6.1 ±10.0	6.0 ± 8.0	6.0 ± 8.0	8.0 ±10.5	6.3 ± 8.5
Hgt Differ.	- 1.5 ± 7.2	- 2.2 ± 6.7	- 0.8 ± 7.7	0.1 ± 7.2	- 3.1 ± 7.0	- 2.0 ± 9.4	- 1.0 ± 4.2
Fore-Aft	10.8 ±12.9	7.9 ±10.3	13.8 ±14.8	10.8 ±12.9	10.9 ±13.3	10.8 ±14.0	10.9 ±12.1
Lum U/D	10.0 ±12.6	12.1 ±13.5	7.8 ±11.6	9.8 ±12.9	10.2 ±12.7	8.7 ±11.3	11.2 ±14.0
Lum I/O	6.4 ± 8.1	6.1 ± 6.3	6.7 ± 9.6	6.5 ± 7.8	6.3 ± 8.5	6.6 ± 8.0	6.2 ± 8.5
Back Angle	4.0 ± 3.4	4.8 ± 3.7	3.3 ± 3.0	3.8 ± 3.0	4.3 ± 3.8	3.7 ± 3.4	4.4 ± 3.5
S W Angle	9.0 ± 6.1	9.6 ± 6.8	8.3 ± 5.3	8.8 ± 6.3	9.2 ± 5.9	9.4 ± 6.3	8.5 ± 5.9

Table 8. Range of seat adjustment travel (in mm and degrees) for the total sample and by strata for sex, generation and stature.

There were no significant differences between any strata for any of the seat adjustment parameters. A two-tailed t-test for equal variances was used to test for differences at the .05 level of significance.

C. Seat Position in the Fixed Back Drive

The fixed back drive was composed of two 45-minute drive segments: an upright seat back and a reclined seat back drive segment. Data were collected at the beginning of the fixed back drive, at 30 minutes and at 45 minutes. If a subject adjusted their seat between 0 and 30 minutes, the adjustment was ignored, as in the Free Drive data collection protocol. If a subject adjusted their seat between the 30- and 45-minute scheduled data collection times, then a complete set of data were recorded. In the fixed back drive we collected data on only two subjects between the 30- and 45-minute interval of the reclined drive and no data were collected outside of the scheduled protocol data collection times for subjects during the upright seat back drive. In addition, this drive, divided into two parts, was conducted to generate two different spinal shapes in each subject with which we would be able to test our spine model developed in the laboratory. As a result, the number of seat positions and length of time in a modal position is of no value. Furthermore, as a consequence of our controlling the seat back angle, the driver did not have as much control over the adjustable seat and vehicle parameters as he or she did in the Free Drive.

In the fixed back angle drives, the seat back angle was fixed at 15° in the upright and 30° in the reclined positions. Each subject was allowed to adjust all other seat parameters, but the on-board computer calculated the seat back angle during each drive segment when any changes were made and corrected the seat for the assigned seat back angle. The adjustable seat parameters were, therefore, the same as in the Free Drive except for back angle. The position of the six adjustable seat and vehicle parameters for the upright drive are reported in Table 9 and for the reclined drive in Table 10. A two-tailed T-Test for samples with equal variances was used to test for differences between strata in the sex, generation, and stature groups. For those comparisons in which the variance was not equal, e.g. above and below average height for fore-aft adjustment in the upright seat back drive, a T-Test for samples with unequal variances was used. An $\alpha<0.05$ was used to identify significant differences between strata.

Variable	Total	Sex		Generation		Stature	
		Male	Female	BB	PBB	Above	Below
Rr Riser H	17.5 ±13.6	16.5 ±14.1	18.5 ±13.4	16.0 ±13.5	19.0 ±13.9	14.6 ±14.6	20.4 ±12.2
Frt Riser H	17.5 ±13.4	17.9 ±14.8	17.0 ±12.4	16.0 ±14.5	19.0 ±12.5	17.9.±.17.6	17.1 ± 8.5
H Differ.	0.0 ±12.7	1.5 ±14.7	-1.5 ±10.4	0.0 ±12.6	0.0 ±13.1	3.3 ±14.2	-3.3 ±10.3
Fore-Aft	32.8 ±36.3	**16.3 ±21.8**	**49.3 ±40.7**	30.8 ±34.6	34.8 ±38.7	**13.5 ±19.6**	**52.1 ±39.3**
Lum U/D	20.9 ±14.7	17.9 ±13.8	23.8 ±15.4	**15.8 ±13.1**	**25.9 ±14.9**	23.2 ±14.8	18.5 ±14.7
Lum I/O	15.8 ± 9.6	13.4 ±10.4	18.3 ± 8.3	14.3 ± 9.43	17.3 ± 9.9	14.3 ±11.3	17.4 ± 7.6
S W Angle	-21.8 ±8.8	-22.0 ± 5.1	-21.6 ±11.4	-23.2 ±11.2	-20.5 ± 5.8	-20.3 ±10.9	-23.3 ±6.2

Table 9. Average (in mm and degrees) and standard deviation of adjustable parameters in the upright drive segment for the total sample and by strata in sex, generation, and stature (numbers in bold are significantly different at the .05 level).

Variable	Total	Sex		Generation		Stature	
		Male	Female	BB	PBB	Above	Below
Rr Riser H	24.9 ±14.3	21.9 ±15.2	27.9 ±13.0	21.1 ±14.7	28.8 ±13.1	25.4 ±14.2	24.4 ±14.8
Frt Riser H	18.4 ±12.6	15.7 ±12.9	21.2 ±12.0	18.1 ±13.1	18.8 ±12.5	19.6 ±13.9	17.3 ±11.4
H Differ.	-6.5 ±13.7	-6.3 ±14.9	-6.7 ±12.8	-3.0 ±15.1	-10.0 ±11.5	-5.8 ±13.7	-7.1 ±14.1
Fore-Aft	56.2 ±46.5	**30.3 ±28.1**	**82.2 ±47.2**	51.8 ±45.1	60.6 ±48.6	**38.5 ±48.1**	**74.0 ±38.1**
Lum U/D	22.8 ±16.7	**17.4 ±15.7**	**28.1 ±16.3**	**16.8 ±15.2**	**28.8 ±16.2**	26.9 ±16.3	18.6 ±16.4
Lum I/O	15.6 ± 9.8	**11.5 ± 9.7**	**19.8 ± 8.2**	**12.1 ± 9.4**	**19.2 ± 9.1**	15.3 ±11.0	16.0 ± 8.7
S W Angle	-21.1 ±8.3	-22.9 ± 5.7	-19.5 ±10.1	-22.3 ±10.5	-20.0 ± 5.7	-19.7 ±10.7	-22.6 ± 5.2

Table 10. Average and standard deviation of adjustable parameters in the reclined drive segment for the total sample and by strata in sex, generation, and stature (numbers in bold are significantly different at the .05 level).

Tables 9 and 10 describing the upright and reclined drive segments respectively share three results in common. There are significant differences in both drive segments by sex for fore/aft adjustment, by generation for lumbar up/down adjustment, and by stature for fore/aft adjustment.

In the reclined drive, however, there are significant differences by sex in the lumbar adjustments, both up-down and in-out, and by generation for lumbar in-out. Although the differences between the two drive conditions were not tested while holding the sex, generation and stature categories constant, large differences are observed. The average differences in fore-aft seat locations between the upright and reclined drives are 14.0 mm and 32.9 mm for males and females respectively. The seat was moved forward in the reclined drive and rearward in the upright drive. The vertical locations of the lumbar support are very similar. The differences in fore-aft locations of the seat in the upright and reclined drives for stature are 25.0 mm and 21.9 mm for the above and below average stature groups respectively.

The distribution of rear riser modal positions in the fixed back drives is depicted in Figure 10. In general, the upright portion of the fixed back drive has subjects evenly grouped throughout the range of rear riser travel. In the reclined seat back drive, however, there is a tendency for the subjects to sit with the seat height raised above the floor.

Error! Not a valid link.

Figure 10. Frequency distribution of rear riser modal positions in fixed back drive (categories in mm).

The frequency distribution of front riser modal positions for thigh support appears to approximate a normal distribution with the average at zero (i.e. equal to rear riser height) and evenly distributed to either side (Figure 11). However, in the reclined position, there are 26 subjects with negative front riser modal positions and 14 with positive front riser positions. This distribution in the reclined position contrasts with a distribution of 19 and 21 subjects in the upright modal position for negative and positive front riser positions respectively.

Error! Not a valid link.

Figure 11. Frequency distribution of riser height difference in modal positions in fixed back drive (categories in mm).

As a result of the change in back angle, there were some subjects who used the forward travel of the seat track in the fore-aft adjustment in the reclined portion of the fixed back angle drive. However, as seen in Figure 12, the distribution is skewed as in the free drive shown in Figure 6.

Error! Not a valid link.

Figure 12. Frequency of fore-aft modal positions in the fixed back drive (categories in mm).

The height of lumbar support in both the reclined and upright portions of the fixed back angle drive is bimodal (Figure 13). Some subjects used the lumbar support in its lowest position and some subjects used it in a high position.

Error! Not a valid link.

Figure 13. Frequency distribution of the lumbar up-down modal positions in the fixed back angle drive (categories in mm).

The in-out modal position of the lumbar support in the fixed back angle drive, however, appears to be a tri-modal distribution (Figure 14). The differences between the reclined and upright usage are minimal.

Error! Not a valid link.

Figure 14. Frequency distribution of lumbar in-out modal positions in the fixed back angle drive (categories in mm).

D. Anthropometric variation in selected modal positions.

Twelve anthropometric dimensions were measured on each driver in the laboratory (ERL-TR-95-002). Correlations between these dimensions and the seven seat package adjustments were made for males (Table 11) and females (Table 12) separately. In general, the females had higher correlations than the males, but the highest correlation in the females was -.795 between sitting height and rear riser height. The highest correlation in the males was -.619 between elbow-hand length and fore-aft seat position.

	Rr Riser	Fr Riser	Fore-Aft	Lum U/D	Lum I/O	Back A.	SW Angle
Stature	-.638	-.354	-.750	.121	-.045	.117	.057
Weight	-.346	-.383	-.571	.302	-.127	.048	-.095
Sitting Hgt	-.795	-.396	-.485	.024	.034	.251	-.162
Sitting Eye Hgt	-.733	-.436	-.481	.100	-.040	.219	-.217
Knee Hgt	-.581	-.323	-.708	.219	.045	.065	.007
Popliteal Hgt	-.612	-.349	-.642	.219	.036	.032	.002
Should.-Elbow L	-.518	-.364	-.723	.219	-.236	.148	.023
Elbow-Hand L	-.541	-.434	-.683	.253	.117	.210	.270
Butt-Popliteal L	-.317	-.494	-.598	.100	-.195	-.167	.151
Shoulder Br	-.233	-.367	-.472	.405	-.098	-.071	-.268
Hip Br	-.287	-.320	-.300	.121	.028	-.024	-.306
Bispinous Br	-.056	-.015	-.120	.102	.098	-.012	-.094

Table 11. Correlations between anthropometry and seat adjustments in the free drive for females.

	Rr Riser	Fr Riser	Fore-Aft	Lum U/D	Lum I/O	Back A.	SW Angle
Stature	-.300	-.060	-.505	.196	-.584	.348	.020
Weight	-.180	.122	-.442	.282	-.131	.219	.358
Sitting Hgt	-.344	-.210	-.303	.022	-.545	.410	.216
Sitting Eye Hgt	-.398	-.264	-.276	.041	-.608	-.264	.170
Knee Hgt	-.339	-.001	-.583	.136	-.499	.260	-.075
Popliteal Hgt	-.347	.014	-.466	.058	-.537	.316	-.153
Should-Elbow L	.082	.353	-.497	.221	-.210	-.008	.111
Elbow-Hand L	-.284	-.021	-.619	.153	-.196	-.006	-.110
Butt-Popliteal L	-.151	.283	-.428	.303	-.451	.369	-.057
Shoulder Br	-.419	.088	-.002	.541	-.253	.412	.402
Hip Br	-.265	-.030	-.582	.114	-.199	-.083	-.083
Bispinous Br	-.149	.050	-.288	.084	-.470	-.034	-.056

Table 12. Correlations between anthropometry and seat adjustments in the free drive for males.

Fore-aft seat position is significantly correlated in males and females with stature, knee height, and elbow-hand length. Since stature is the most easily obtained dimension from these three anthropometric measurements, a scatter plot between stature and fore-aft seat position is reported in Figure 15. Fore-aft seat position, it should be recalled, is measured with zero at the rearmost seat position. The slopes of the trend lines for females indicate that females use a greater range of fore-aft seat position than do males.

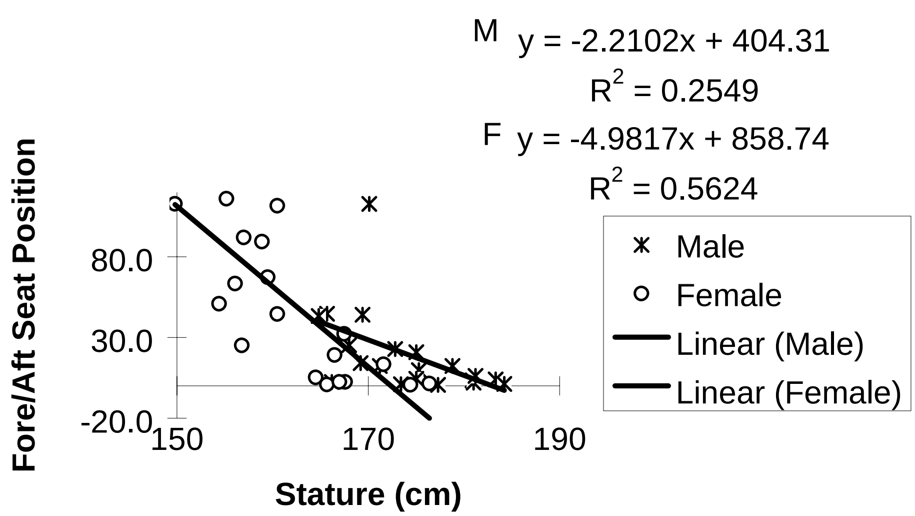

Figure 15. Relationship between fore-aft seat modal position in the free drive and stature for males and females.

Although the highest correlation in both males and females is -.795 between rear riser and sitting height for females, the correlations between rear riser and sitting eye height is -.733 and -.398 for females and males respectively. There is a slightly higher correlation between sitting eye height and rear riser height in males than between sitting height and rear riser height. A scatter plot of the data representing the relationships between sitting eye height and rear riser height is presented in Figure 16. The zero position for rear riser height is at the lowest position closest to the floorboard.

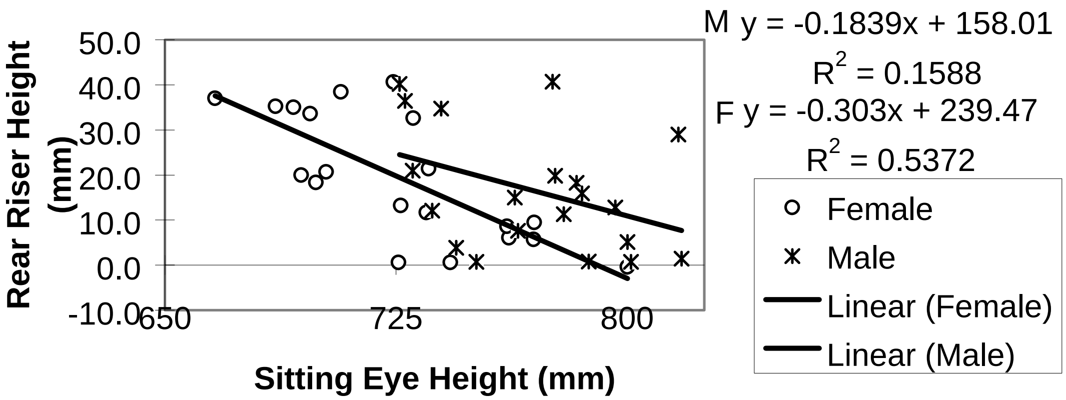

Figure 16. Relationship between rear riser height modal position in the free drive and sitting eye height for males and females.

Although the relationships between lumbar in/out position and anthropometric dimensions is low, the average correlation for females is -.032 and for males, -.398. The highest correlation, -.608 is with sitting eye height that is depicted in Figure 17.

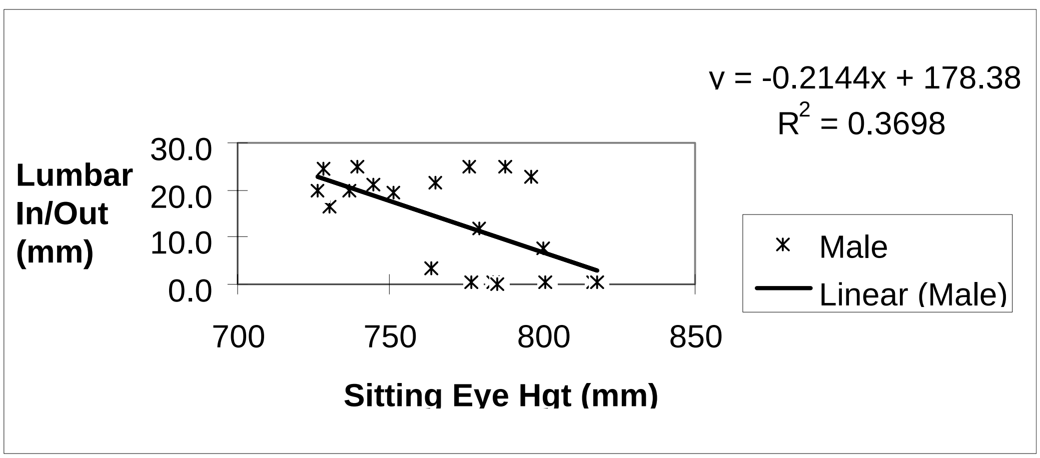

Figure 17. Relationship between lumbar in/out modal position in the free drive and sitting eye height for males.

E. Comfort and Selected Modal Position

When the concept of comfort is incorporated in the results, another parameter associated with time must be considered. That is, the occupant's comfort state is not static, but dynamic, and the comfort parameter must be considered in at least two states. Thus, the occupant may be comfortable (C) or uncomfortable (U) at either the beginning or end of the modal period. This change of comfort state means that there are four groups of occupants who must be considered and the change of modal seat position must be evaluated relative to these four comfort states: CC, CU, UC, & UU.

The occupant's state of comfort was measured with the verbal questionnaire [7] which asked if the occupant was comfortable or uncomfortable according to the protocol described in the ERL-TR-95-001 [1]. The results were recorded on tape by the ride technician who also inquired relative to the source of the occupant's discomfort and asked the occupant to rate their level of discomfort from 0 to 10. The results were coded in a database and stored relative to the time during the drive that the questions were asked. These times were correlated with the data collection log for all data files stored on the on-board computer during the drive. Thus, the relationship between occupant comfort and seat position was determined by time during the drive. The questions were generally asked within 1-2 minutes of data collection with two exceptions for whom the seat position data were collected twenty minutes prior to the comfort data. In addition, there were seven cases for which there were no comfort data due to equipment failure and/or noise on the tape recorder.

There were 33 complete cases when the sample of 40 was stratified between the four comfort groups of CC, CU, UC, and UU representing comfort or discomfort at the beginning ("B") or end ("E") of the modal drive period (Table 13). The data are presented in pairs representing the beginning (B) and end (E) of the modal period drive for rear riser height, front riser height, fore-aft seat position, lumbar up/down, lumbar in/out, back angle, difference in riser height (Front - Rear), and steering wheel angle. The rating is the comfort level on a scale of 0 to 10 (ERL-TR-95-004) described by the occupant at the time the data were collected. The data in selected modal positions are in millimeters and degrees and the magnitudes of travel for each adjustment parameter are significantly different (Table 1). As a result, to determine whether seat adjustments over time are related to comfort and the changing state for each individual, additional analysis must normalize and remove the effect of the changing dimensional scales upon the results. The data are, therefore, normalized for the change in seat position for each measured parameter from the beginning to the end of the modal position. Normalization uses the average range of seat adjustment (Table 8) used by all forty subjects.

Variable	CC	CU	UC	UU
Rear Riser-B	17.5 ±14.1	20.6 ±14.7	18.7 ±18.5	18.0 ±12.0
Rear Riser-E	17.7 ±14.3	20.6 ±14.6	20.5 ±18.3	19.8 ±12.5
Front Riser-B	13.3 ± 8.8	16.1 ±15.8	23.2 ±17.5	20.9 ±16.6
Front Riser-E	14.1 ± 9.1	16.2 ±15.8	23.0 ±17.7	22.2 ±12.7
Fore-Aft-B	36.9 ±35.5	24.2 ±27.9	56.4 ±69.4	49.3 ±43.5
Fore-Aft-E	36.7 ±34.9	24.0 ±27.9	57.0 ±69.3	45.5 ±38.9
Lumbar-U/D-B	8.7 ±12.6	18.6 ±14.6	9.2 ± 9.5	18.7 ±14.9

Lumbar-U/D-E	9.2 ±12.6	18.7 ±14.4	10.7 ± 8.7	17.8 ±13.2
Lumbar-I/O-B	15.7 ± 9.3	16.0 ±10.2	11.0 ±11.3	18.3 ± 8.9
Lumbar-I/O-E	16.8 ±10.3	16.4 ±10.4	13.2 ±10.9	19.0 ± 7.1
Back Angle-B	19.2 ± 4.7	15.8 ± 5.2	19.1 ± 3.0	18.9 ± 4.2
Back Angle-E	19.8 ± 5.0	15.9 ± 5.2	18.9 ± 1.8	18.3 ± 4.8
Riser Dif-B	4.2 ±11.9	4.5 ±14.2	- 4.6 ±15.0	- 2.8 ±18.1
Riser Dif-E	3.6 ±11.5	4.5 ±14.0	- 2.5 ±14.2	- 2.4 ±17.0
SW Angle-B	-28.4 ±7.6	-29.9 ±12.4	-27.3 ± 4.4	-27.4 ± 7.6
SW Angle-E	-22.2 ± 7.5	-24.9 ±12.5	-26.3 ± 4.2	-26.3 ± 5.9
Rating-B	0.0 ± 0.0	0.0 ± 0.0	2.5 ± 1.3	4.6 ± 2.1
Rating-E	0.0 ± 0.0	3.2 ± 1.6	0.0 ± 0.0	4.5 ± 1.8

Table 13. Average and standard deviation for modal period seat positions by comfort group.

Due to the small sample size (N=33 with complete data), a reduction in the number of variables is essential to investigate the relationship between change in comfort state and seat position. Thus, with these normalized data, four new parameters were defined that represented the total amount of seat position movement in the vertical and horizontal directions (SeatPos), total amount of lumbar adjustment in the vertical and horizontal directions (Lumbar), total angular adjustment in the seatback and difference between front and rear riser heights (Angle) and finally with the normalized steering wheel angle (SW). The equation for seat position is defined as follows:

$$SP = \frac{|FA_B - FA_E|}{|\overline{FA}_R|} + \frac{|RB_B - RB_E|}{|\overline{RB}_R|} + \frac{|FR_B - FR_E|}{|\overline{FR}_R|} \qquad [1]$$

where SP is the sum of the three seat position parameters in the vertical and horizontal directions. The subscripts “B” and “E” identify the seat adjustment position at the beginning and end of the modal seat position period and the superscript bar over the FA represents the average range (R) for the adjustment. FA is the fore-aft position; RB is the rear riser height; and FR is the front riser height.

The relationship between the changes in the vertical and horizontal positions of the lumbar support in the seat back and comfort were investigated by calculating a variable that represents the total amount of adjustment in the lumbar support. The equation to calculate this change in lumbar support was calculated as follows:

$$Lumbar = \frac{|LUD_B - LUD_E|}{|\overline{LU}_R|} + \frac{|LIO_B - LIO_E|}{|\overline{LIO}_R|} \qquad [2]$$

where LUD is the up-down position of the lumbar support and LIO is the in-out position of the lumbar support.

The relationship between the changes in angular position in the seat were calculated from two adjustment parameters: back angle and the difference in front and rear riser heights, i.e. seat cushion angle. The equation to calculate this change in angular adjustment was calculated as follows:

$$Angle = \frac{\left|BA_B - BA_E\right|}{\left|\overline{BA}_R\right|} + \frac{\left|RD_B - RD_E\right|}{\left|\overline{RD}_R\right|} \qquad [3]$$

where BA is back angle and RD is riser height difference calculated by subtracting the front riser height from the rear riser height.

The change in the steering wheel position was calculated by simply subtracting the absolute value at the end from the beginning location of the steering wheel during the modal position and dividing this difference by the average range of adjustment in the steering wheel. Thus, the calculation was as follows:

$$SW = \frac{\left|SW_B - SW_E\right|}{\left|\overline{SW}_R\right|} \qquad [4]$$

where SW is steering wheel angular position.

The results of univariate F tests show that Seat Position and Angle are statistically significant at $\alpha \leq .05$ (Table 14). A multivariate Anova was used to test for the relationship between the dependent variables of Seat Position, Lumbar and Angle and the independent variable of comfort in the general linear equation

$$Y = XB + E \qquad [5]$$

where Y is a matrix of dependent variables, X is a matrix of independent variables (CC, CU, UC, and UU) and E is a matrix of random errors [8].

Variable	Least Squares Means				Univariate F Tests	
	CC	CU	UC	UU	F-Ratio	P
Seat Pos	0.250	0.126	0.741	1.866	4.829	0.008
Lumbar	0.229	0.085	0.479	0.647	2.803	0.057
Angle	0.685	0.288	1.969	3.150	6.375	0.002
TOTAL	1.164	0.499	3.189	5.663	NA	NA

Table 14. Results of univariate F tests for differences in change of comfort associated with adjustments in normalized seat position variables.

Three multivariate test statistics were calculated, Wilks' Lambda (F=3.164, P=0.003), Pillai Trace (F=2.406, P=0.017), and Hotelling-Lawley Trace (F=3.884, P=0.001), and all of them were statistically significant. As a result, additional discriminate analysis used canonical coefficients to compute discriminant scores for the four strata within the comfort factor. The discriminant scores were used to predict membership in one of the four groups. The results define a four by four frequency table that contains only three cells with $n \geq 5$. A scatter plot of these results illustrates that those subjects in groups CC and CU cluster very closely about a mean change of zero in seat position. The UC and UU subjects are scattered with a wide range in delta values for seat position. Unfortunately, chi-square tests are unreliable when more than 1/5 of the cells have frequencies less than 5. However, the predicted groups for each of the comfort strata were tested with a Pearson Chi-Square (P=0.000), Likelihood ratio chi-square (P=0.000) and McNemar symmetry chi-square (P=0.891).

Since there are four distinct groups of comfort states in the forty subjects, the relationship between lengths of time in the modal position (Table 4) was examined. A one-way analysis of variance test found statistically significant differences between the groups (Table 15). A Tukey test of multiple comparisons between the lengths of time among the four groups reveals that the UU group is statistically significant at the .05 level of significance.

	CC	CU	IC	UU
Length (min.)	51.6 ±4.5	49.9 ±4.5	46.2 ±6.0	33.7 ±4.3

Table 15. Length of time in modal position for four comfort strata.

IV. Discussion

Seat position has long been understood by everyone to be a critical parameter for vehicle operation and operator comfort. If the seat cannot be adjusted within tolerable driver reach dimensions, the driver will have trouble operating the vehicle safely and sitting comfortably. The initial planning for this study, however, did not anticipate finding significant results in the seat position data because the selected seat for the driving test had considerable travel with electronic controls for the operator.

The controls for the seat were placed carefully beside the seat so that they were easily understood and operated the seat in the direction of control movement. Thus, for those subjects who did not have experience with so-called "six-way" power seats, the intuitive operation of the seat and its controls was carefully considered. As a result, there were no complaints about either the control operation or their placement.

Most subjects did not move the seat a great deal, or "play" with the seat and its controls. Especially by the time they made their comfort drive for 2 hours, they had already experienced approximately 2 hours driving the vehicle. As a result, the average number of files per subject, 6.4 (Table 5) was expected. However, when the displacements and time between adjustments were considered in the analysis, the average number of files was not a good indicator of the amount of adjustment made by the subjects. The average number of seat positions considered unique according to our criteria of displacement (1 mm) and time (1 minute) were 4.4. However, subjects tended to make more than one adjustment per change in seat position. The average number of parameters adjusted was 11.5 which means that approximately 2.6 adjustments were made for every change in seat position. This number of adjustments reflects the coupling between parameters in the seat. This coupling phenomenon, if it exists and is consistent, represents a new area of investigation for seating ergonomics.

As was expected, the vertical and horizontal locations of the seat were highly variable, depending primarily upon body size, but there were also some differences by age and sex that were not associated with sexual dimorphism. For example, in Table 7, males placed the lumbar support in a statistically significant lower position than females. There was also a rather remarkable difference in the use of front and rear risers between the sexes. Although the difference was not statistically significant, females tend to raise the rear riser above the front riser whereas males tend to raise the front riser above the rear riser. The net effect of this difference between front and rear riser heights is to effectively shorten, for females, and lengthen, for males, the length of the contact between the thigh and seat cushion. Thus, we have referred to the front riser as a source of thigh support (Figure 5) and the rear riser as the primary source of seat height control (Figure 4).

In most of the seat position variables, there was a tendency to not use the full extent of the travel. In particular, the extended travel of the fore-aft seat track was not used in its position closest to the accelerator (Figure 6). In fact, the skewed distribution appears to be truncated in the rearward direction that implies that the drivers would have preferred greater rearward travel.

With respect to the use of lumbar support, there was considerable use of the full travel of the support in both up-down (Figure 7) and in-out directions. As previously noted, there is a statistically significant differences in the up-down location by sex, but there are no differences by age or stature in the up-down location. There is, however, a statistical difference in the in-out location of the lumbar support by stature. The above average stature wants a less protruding lumbar support than the below average stature (Table 7). As illustrated in the Figure 6, however, the full range of the in-out adjustment of the lumbar support is used.

The fixed back drive was originally planned to test the differences in posture as part of the evaluation of our spinal model. In general the use of the seat in the fixed back drive is comparable to the use of the seat in the free, comfort drive except that the sex differences in the use of the front riser height to provide thigh support disappear. However, statistically significant differences are observed by sex and stature for fore-aft seat location, by generation for lumbar up-down location in both the upright (Table 9) and reclined (Table 10) drives. In the reclined drives, the lumbar up-down and lumbar in-out are significantly different between sex and age groups. It is clear in Figures 12 and 13 that the lumbar support is used in its full range thereby suggesting that adjustability in the up-down direction is valuable to the driver.

The relationship between seat position and body size was examined more thoroughly with a few anthropometric dimensions. From the twelve anthropometric dimensions measured on these subjects (ERL-TR-95-002), only riser height and fore-aft seat location have correlations greater than .7 with any anthropometric dimensions. Within this analysis, only female subjects have correlations greater than .7; the highest correlation in the male data (Table 12) was -0.619 between Elbow-hand length and fore-aft seat position.

Perhaps of greater interest to packaging are the results of the regression analysis seen in Figures 14-16. This analysis shows that females use a greater range of seat position in the fore-aft location than males. In addition, males use a smaller portion of the fore-aft seat position because they are larger and sit closer to the rearmost seat position. The resulting slope of the regression line representing the change in fore-aft position with stature indicates a need for more rearward motion of the seat. Theoretically, there is no reason for the different slopes between males and females in the relationship between seat fore-aft position and stature since this relation is based solely on geometric relationships. For example, the relationship between riser height and sitting eye height, which is also a geometric relationship, does not show a large difference in slope between the sexes. Thus, the flatter slope in Figure 14 depicting the relationship between fore/aft seat position and stature for males is due mainly to the restricted travel of the seat rearward and the consequent “bunching” of the data in the rearward seat positions.

Of a more general nature, however, are the interesting results of the comfort analysis. Seat position is an independent variable in the occupant/vehicle interface that is clearly related to comfort. That is, if a driver cannot place the seat in a position that optimizes the geometric requirements to operate the vehicle, the driver will find the vehicle difficult to operate over a long period of time. We have long recognized that one of the greatest strengths of the “human race” is its incredible adaptability. However, as we have evolved into consumers who expect the environment to minimize pain and maximize pleasure regardless of the job, our patience with inefficient design has diminished to the point of not accepting many of our former conditions. Consequently, a successful seat and package design has to include the ability to optimally position the seat for each driver, regardless of differences in age, sex, or body size.

The basic problem in this investigation was, however, to reduce the massive amount of information into a manageable task. The experimental design was created to measure comfort while the driver was operating the vehicle on the highway. The only source for measuring driver comfort, however, is the verbal response of the driver. Consequently, we decided to solicit this information, whether the driver voluntarily spoke of discomfort or not, at fixed intervals or when the seat was re-positioned. This logic was based, in part, on the preceding perceptions that people will seek an optimal position in which to engage in any activity and being unable to find it will describe their perception of the environment to be uncomfortable. As a result, a verbal question, "Are you comfortable? was asked every time the seat was re-positioned or at the fixed intervals described previously in ERL-TR-95-001. This functional definition of comfort, however, means that comfort is a dynamic, rather than static state of mind in the occupant.

A dynamic state of comfort relative to the modal position previously discussed means that the seated occupants have four choices based upon whether they are comfortable or uncomfortable at the beginning or end of the modal position driving period. Thus, four categories of comfort states are possible and we have used abbreviations to designate them as CC, CU, UC, and UU. The first letter represents the beginning and the last the end of the modal period. Using these categories, the modal position, by comfort group, has some interesting properties.

There are 33 subjects with complete comfort and seat position data. Within the four categories, nine (9) are in the comfortable group (CC), five in UC, 9 in CU and 10 in the uncomfortable group (UU). The UU group has the greatest amount of change in seat position between the beginning and end of the modal position and the UC group has almost as great of normalized movement from beginning to end of modal position as the UU group (Table 12). In contrast to the change in seat position, the drivers in groups CC and CU change in steering wheel angle more than the drivers in groups UC and UU (Table 13). Thus, it appears that the uncomfortable groups (UU and UC) are continuing to seek an improved seat position whereas the comfortable groups (CC and CU) have found a comfortable seat position. This conclusion is re-affirmed by the results shown in Table 12 where the three general variables of seat position, lumbar position, and angular position are analyzed. The sum of the total normalized movement goes from 1.1 units in the CC group to 5.7 units in the UU group. Unfortunately, the sample size is too small to thoroughly analyze with confidence the results of these data, but the trend is certainly present in all of the comfort data analysis. Seat position is important for occupant comfort.

V. Conclusions

In general, modal position is a new concept in seat comfort investigations. The idea of a modal position, however, affects future seating investigations in that it shows that time in the seat is important in evaluating a seat. The evaluation of occupant's seated comfort must be based upon sufficient time for the occupant to identify his or her optimal seat position. In this seat position, however, the data must be analyzed to determine occupant position, occupant posture, occupant muscle fatigue, and occupant comfort. All of these factors contribute to the overall evaluation of the seat by the occupant. Any subsequent changes in the design of the seat, however, should be based upon results from individuals who have clearly, in all data, found a comfortable, i.e. stable, seat position in the particular vehicle package. In this investigation, we have 27.3% of our subjects in a comfortable state throughout their modal position. The rest of the subjects were divided between 42.4% of the subjects who were mixed (UC and CU) in their comfort state and 30.3% of the subjects who were uncomfortable. Thus, approximately 1/3 to 3/4's of the subjects have results that describe the failure of the seat or some attributes of the package to establish and maintain a comfortable state while operating the vehicle. Whether this information is available from laboratory studies in which the "driver" sits in a seat for a short period of time is clearly a question mark. Seat and package design must be based on a program that establishes a greater proportion of comfortable occupants than uncomfortable occupants.

This investigation selected subjects from the market population that had bought vehicles similar to the mid-size vehicle used on the drives. Differences in the market population according to age, sex and body size are also reflected in the data on seat position usage. Vehicle packaging accommodates most of these differences, i.e. range of adjustment in seating parameters. However, it is important to note that some of the adjustments affect seat size and subsequent occupant comfort. In particular, women who have shorter legs than men tend to drop the front of the seat below the rear of the seat. This difference in riser height is used to effectively shorten the seat cushion to accommodate shorter leg length. Thus, the six-way power seat has features that affect occupant comfort and should be considered in the design of the seat and vehicle packaging parameters.

In conclusion, results from driving tests are direct measures of the occupant's actual preference in posture, position and comfort levels. Within the nine comfortable subjects in our investigation, a comfortable seat position was obtained. In the remaining 24 subjects (72.7%), a comfortable occupant state was not obtained by ten subjects during their modal seat position period and the remainder, 14 subjects, were unable to sustain a comfortable state during their modal period. We conclude from these data that adjustable seat positions cannot make up for an uncomfortable seat and/or package. Without these data, the relative effects of seat design and packaging variables upon occupant comfort are extremely difficult to understand. The data reported in this document, however, must be considered limited to the mid-size vehicle in which they were collected until additional vehicles of different packaging dimensions are investigated. It is expected that basic concepts developed in this report will be equally valid in other packages and that the equipment and procedures developed for the mid-size vehicle are equally applicable to other motor vehicles. However, the specific use of these data on the driver's seat and its effects on comfort level in a predictive model for seat design and vehicle packaging will have to await additional data and vehicle laboratory investigations of other vehicle packages and seat designs.

List of References

[1] Reynolds HM, Brodeur R, Eppler M, Neal D, Rayes K, Kerr R, Stockman G. The Initial Position and Postural Attitudes of Driver Occupants. Experimental Protocol. ERL-TR-95-001, Ergonomics Research Laboratory, Technical Report, Michigan State University, East Lansing, MI. 1995.

[2] Eppler M, Bolster V, Reynolds HM. The Initial Position and Postural Attitudes of Driver Occupants. Anthropometry. ERL-TR-95-002, Ergonomics Research Laboratory, Technical Report, Michigan State University, East Lansing, MI. 1995.

[3] Roe RW. "Occupant Packaging," pp11-42. In, B. Peacock & W. Karwowski (eds) Automotive Ergonomics. Taylor & Francis, Washington, D.C. 1993.

[4] Reynolds HM. "Automotive seat design for sitting comfort," pp 99-116. In B. Peacock & W. Karwowski (eds) Automotive Ergonomics. Taylor & Francis, Washington, D.C. 1993.

[5] National Semiconductor General Purpose Linear Devices Databook. National Semiconductor Corporation, 2900 Semiconductor Drive, Santa Clara, California. 1989.

[6] Maxim 1986 Power Supply Circuits. Maxim Integrated Products, Inc., 510 N. Pastoria Ave., Sunnyvale, CA 1986.

[7] Eppler M, Reynolds HM. The Initial Position and Postural Attitudes of Driver Occupants. Questionnaires. ERL-TR-95-004, Ergonomics Research Laboratory Technical Report, Michigan State University, East Lansing, MI. 1996

[8] SYSTAT for Windows: Statistics, Version 5 Edition. Evanston, IL: SYSTAT, Inc., 1992, 750pp.

[9] Gordon CC, Churchill T, Clauser CE, Bradtmiller B, McConville JT, Tebbetts I, Walker TA. 1988 Anthropometric Survey of US Army Personnel: Methods and Summary Statistics. Technical Report Natick/TR-89/044. United States Army Natick, Research, Development and Engineering Center, Natick, MA., 1989.

[10] "Chart-Seat Master Complete, Front & Rear." Drawing #16726108, Sheet 1 of 4.

[11] "Seating Arrangement." Drawing #20584405, Layout IL-43686, 1990-91 Chevrolet Sedan, 1WM69.

[12] Neal DR, Bolster V, Kerr R Generating a computer model of the SAE 2D H-point template. Technical Report, ERL-TR-95-004. Ergonomics Research Laboratory, Michigan State University, 1995.

[13] Industrial Metrecom Manual. Model IND-01, Version 2.0. Faro Technologies, Inc., Lake Mary, Fl., 1993.

Appendix A

Seat Adjustment Parameters at Beginning and End of Modal Position including Driver Comfort level.

Table A. Location of Seat Adjustable Parameters at beginning of Modal Position.

ID	Sex	Age	Stature	Rear	ForAft	Lumud	Lumio	Front	BackA	SW	DifRiser	Comfort	Rating
1	F	B	B	20.7	67.4	38.0	25.0	2.6	12.7	-31.9	18.1	C	0
2	F	B	B	33.6	50.9	19.3	16.7	16.0	11.1	-26.6	17.6		
3	F	B	B	21.4	92.0	19.7	15.1	0.6	15.5	-27.0	20.7	U	9
4	F	P	B	35.2	146.8	24.1	9.8	41.0	18.9	-34.1	-5.8	U	1
5	F	P	B	35.0	89.5	3.9	21.2	40.9	13.8	-31.4	-5.9	C	0
6	F	B	A	11.7	0.9	28.7	17.7	0.8	21.7	-28.9	10.9		
7	F	P	A	5.7	1.4	14.3	0.4	19.7	19.5	-27.3	-14.1		
8	F	P	B	37.0	112.8	5.9	19.8	26.8	18.4	-21.3	10.2	C	0
9	F	P	B	18.3	44.5	5.1	20.6	18.1	11.8	-22.3	0.2	C	0
10	F	B	B	0.6	116.0	5.3	25.0	29.4	21.6	-27.0	-28.8	U	4
11	F	B	A	-0.4	0.6	0.0	21.1	9.4	16.2	-22.6	-9.8		
12	F	P	B	38.4	63.5	0.3	10.9	30.9	19.8	-33.5	7.6	U	4
13	F	P	A	32.6	2.4	36.3	28.8	11.7	22.1	-16.3	21.0		
14	F	B	A	9.5	13.4	31.6	25.0	0.6	11.3	-44.1	8.9	C	0
15	F	P	A	6.0	32.2	38.0	25.0	16.7	15.9	-39.4	-10.6	U	4
16	F	P	B	40.6	25.0	38.0	0.7	0.8	8.8	-43.8	39.9	C	0
17	F	B	A	0.5	19.2	0.5	3.7	11.6	25.1	-28.7	-11.1	C	0
18	F	B	A	8.6	111.7	29.3	24.7	0.0	24.4	-32.0	8.7	U	5
19	F	P	A	20.0	5.2	27.3	28.7	-0.4	12.6	-16.7	20.4	U	4
20	F	P	A	13.2	2.4	18.6	7.1	2.9	16.7	-16.8	10.3	C	0
21	M	B	B	20.9	44.7	2.3	16.3	16.9	17.9	-22.3	4.1	U	2
22	M	B	A	19.8	9.9	38.0	0.3	19.0	23.3	-33.5	0.8	C	0
23	M	B	A	29.0	3.4	0.0	0.4	13.3	19.1	-32.1	15.7	C	0
24	M	P	B	36.4	44.2	4.0	24.5	26.0	24.3	-27.0	10.4	C	0
25	M	B	B	7.6	14.2	10.5	21.6	13.7	18.8	-25.4	-6.2	C	0
26	M	B	A	12.8	20.9	14.2	22.6	9.1	18.7	-5.4	3.7	C	0
27	M	B	A	0.7	4.0	0.5	0.4	4.0	17.9	-39.2	-3.3	U	7
28	M	P	A	0.8	2.1	0.7	25.0	33.0	24.6	-34.3	-32.2	U	2
29	M	P	B	34.7	22.8	38.0	25.0	40.9	14.7	-26.9	-6.2	U	5
30	M	P	B	0.7	25.2	0.1	19.4	15.5	24.5	-28.9	-14.8	C	0
31	M	P	A	15.0	0.7	2.5	3.4	15.9	15.1	-34.4	-0.9		
32	M	P	B	40.2	2.5	3.5	19.9	36.4	14.4	-26.8	3.7	U	2
33	M	P	B	3.9	12.3	14.3	21.0	1.6	13.0	-39.4	2.3	C	0
34	M	B	A	1.4	12.3	13.0	0.4	4.3	21.8	-26.8	-2.9	U	3
35	M	B	A	5.2	1.2	22.2	7.8	13.8	22.3	-27.0	-8.7	C	0
36	M	B	B	40.7	1.1	0.2	25.0	41.0	19.8	-22.3	-0.3	C	0
37	M	P	A	18.3	6.3	23.1	0.3	42.0	22.4	-16.1	-23.7	U	6
38	M	P	B	12.1	43.4	0.5	19.7	6.8	12.9	-43.8	5.3	C	0
39	M	B	A	15.9	4.4	0.3	0.2	4.9	19.0	-21.7	11.0	U	
40	M	B	B	11.3	112.9	8.3	11.8	28.2	20.9	-25.5	-16.9	U	

Table B. Location of Seat Adjustment Parameters at end of Modal Position.

ID	Rear	ForAft	Lumud	Lumio	Front	BackA	SW	DifRiser	Comfort	Rating
1	20.7	67.3	38.0	25.0	2.6	12.3	-32.0	18.1	C	0
2	34.7	61.1	22.8	19.1	18.6	13.5	-23.0	16.1		
3	36.3	75.6	19.6	19.2	21.1	13.4	-27.1	15.2	U	7
4	38.7	147.8	24.1	13.3	40.9	18.1	-31.5	-2.2	C	0
5	34.8	89.6	3.9	21.2	40.8	14.2	-32.4	-6.0	U	4
6	11.4	1.1	28.6	17.6	0.8	21.6	-16.7	10.6		
7	5.7	1.2	14.3	0.4	19.5	19.9	-27.4	-13.8		
8	37.2	111.0	6.9	22.7	27.0	20.5	-16.2	10.2	C	0
9	18.8	44.5	6.4	23.9	18.7	13.9	-16.9	0.2	U	5
10	1.4	115.8	7.3	25.0	28.2	20.5	-29.7	-26.8	C	0
11	-0.6	-0.5	-0.3	24.3	9.5	17.8	-18.5	-10.1		
12	38.1	63.3	6.2	19.0	30.6	19.6	-34.2	7.5	U	5
13	32.3	2.3	35.9	28.7	11.8	21.3	-16.5	20.5		
14	9.5	13.3	31.6	25.0	0.6	10.6	-32.6	8.9	U	5
15	6.3	40.7	38.0	25.0	21.8	17.1	-27.1	-15.5	U	5
16	39.9	21.8	37.4	0.6	0.7	8.5	-36.1	39.2	U	3
17	0.5	19.2	0.4	3.7	11.7	24.5	-16.5	-11.2	C	0
18	10.4	93.6	20.0	19.3	3.9	26.0	-29.8	6.5	U	5
19	27.8	7.3	22.1	24.8	-0.3	9.3	-21.2	28.1	U	4
20	13.5	4.9	18.8	7.2	3.2	16.6	-16.8	10.3	C	0
21	21.0	32.5	2.3	16.3	17.0	16.6	-22.2	4.0	U	2
22	19.7	9.7	38.0	0.3	19.0	23.2	-22.2	0.7	U	2
23	29.3	3.2	0.0	0.4	19.1	20.8	-32.3	10.2	C	0
24	37.2	43.6	4.9	28.3	26.7	26.1	-16.8	10.6	C	0
25	7.7	11.4	12.9	25.0	14.1	20.3	-20.6	-6.3	C	0
26	13.1	21.8	14.1	22.6	9.6	18.3	4.4	3.5	U	2
27	0.7	3.9	0.5	0.3	4.2	18.3	-26.6	-3.5		
28	0.8	2.2	0.4	25.0	23.6	22.3	-33.9	-22.8	U	2
29	25.6	22.6	37.6	25.0	36.7	16.2	-30.0	-11.1	U	5
30	0.8	25.7	0.1	19.4	15.6	24.4	-16.5	-14.8	C	0
31	15.0	0.7	2.5	3.4	15.9	15.0	-22.5	-0.9		
32	41.0	2.9	4.4	23.1	37.4	16.5	-21.6	3.6	C	0
33	3.8	12.8	14.3	20.9	1.4	12.8	-27.4	2.4	U	2
34	6.5	7.2	14.4	3.7	3.7	20.9	-25.4	2.8	C	0
35	5.0	1.2	22.1	7.8	13.7	23.2	-27.5	-8.7	U	1
36	41.0	1.2	0.2	25.0	41.0	18.8	-33.6	0.0	U	5
37	19.5	5.1	21.4	2.3	38.1	19.6	-16.5	-18.6	U	7
38	12.1	44.3	0.5	19.7	6.9	13.0	-31.8	5.2	C	0
39	14.7	11.3	3.1	1.0	4.9	18.4	-23.1	9.9	C	0
40	11.7	111.7	10.4	13.6	29.0	22.6	-20.7	-17.3	U	3

APPENDIX B

In-Car Analog Processing Board

Circuit