An Automotive Lower Back Seat System Design

by

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Science

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ABSTRACT

The goal of this work was to study the effect of different materials used in lower back support systems in automotive seats. The recyclability of materials used in seat cushions is presented as well along with the optimization of their design for assembly as well as disassembly. Gaining the understanding needed to move forward required substantial investigative learning up front. The primary vehicles for this were (1) literature searches, (2) conversing with experts (academic and otherwise) at the forefront of research and design in the area of seat development, and (3) contact with existing users of automotive seats.

Although some of the concepts considered were novel, the final concepts represent ideas more in the mainstream of current seat design practices. One design (the CushAire lumbar support system) is presented in this report. The CushAire design consists of an orthopedically shaped inflatable/deflatable composite foam cushion which, when actuated by the user by depressing a single button, vents air through a single valve allowing the cushion to take the shape of the individual's lumbar region while providing uniform support. The design philosophy here was to combine a device which is capable of providing physiologically correct support with a second device which can distribute this support dependent upon body type and customer preference.

The CushAire design relies upon a composite foam structure to provide physically-correct support that is compliant enough to match different body types. The front layer of foam in the inflatable/deflatable cushion provides compliance dependent upon body type and individual preference while the rear cushion provides support for the lumbar region.

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1. INTRODUCTION

For many casual vehicle drivers, the only reason to think about car seats is to complain about their lack of comfort and support after a longer than normal trip. Many car owners have simply learned to tolerate less-than-comfortable seats as the price of buying less expensive cars. The initial work for this thesis was done while a teaching assistant in 3.59J in a multifunctional design group consisting of Lindsay Anderson, A.S. (Ed) Cheng, Uwe Muller, Lu-Chang Qin, Jonathan G. Sterrett, and myself in the spring of 1992. Since then this work has been extended by me and includes additional work related to the recycleability of seat cushions (section 2), vibrational effects on humans related to seating (section 4.6), driving fatigue parameters (section 4.7) and design for disassembly (section 3).

Are car seats important ? There are several reasons why better seat designs are important to both customers and automakers. First, seats are the third most costly item in the assembly of an automobile. Automakers are concerned about how to lower the cost of the seats, while maintaining comfort and style. Second, because of comfort and issues of car styling, car seats are often a deciding factor for purchase decisions. As a matter of fact, since initial seat comfort is one of the few aspects of an automobile a potential buyer can judge in a short amount of time, seats take on an even more important role. In recent years the population has become more conscious of back ailments and the need for correct posture, which means a greater emphasis on seat comfort and design.

Determining factors of seat comfort range from scientific, measurable facts such as the physiologically correct posture of a human, to the completely qualitative issue of individual preference for seating comfort. Any attempt to maximize the comfort of an automobile seat must consider both of these sometimes divergent requirements. In an attempt to limit the variables associated with this effort, this work concentrates on the lumbar (lower) region of the back and the associated seat support system.

The following report outlines the final design of an improved lumbar support system for automobiles and the process which was used to develop these new concepts. Additionally this reports discusses the recyleablity of seat cushions and design for manufacturing and disassembly methods. Customization and adaptable comfort were foremost in the design of the lumbar support system. The system utilizes the concept of an "air cushion" with a sculptured cushion support to fit the natural curvature of the spine. In addition to the shape

of the cushion, the firmness of the support can be customized for the car buyer. After deciding to purchase a new car from a dealer, a car buyer is fitted for a lumbar support system. Each cushion can then be retrofitted into a seat fabric compartment at the dealership. Within minutes, the customer receives a customized seat ideal for his/her needs.

2. RECYCLABILITY OF MATERIALS USED FOR AUTOMOTIVE SEATING CUSHIONS

The recovery, reuse and recycling of solid waste has emerged as one of the most critical issues facing the global automotive industry. Landfill site reduction and legislative activity created interest within the plastic industry, but limited concrete action.

Things has dramatically changed with the declaration by German manufacturers, Volkswagen, Ford, and Opel to offer to recycle vehicles at the end of their useful life. At this point, the environmental reuse of materials has become a competitive marketing tool. In addition material selection criteria were suddenly and irreversibly modified. The plastic industry is now aggressively seeking cost effective reprocessing solutions and commercially viable outlets for recovered materials.

2.1 FORCES DRIVING RECYCLABILITY

The significance of being able to reuse or recycle high percentage of post-consumer or post-producers materials in polyurethane foam will be discussed in this section, Faced with the prospect of shrinking landfill sites and escalating landfill costs, potentially regulatory legislation, OEM involvement in dismantling and recovery and emerging OEM marketing strategies, it becomes significantly more important to recycle and reuse materials.

Landfill Capacity and Associated Government Action

The shrinking number of landfill sites and the reclassification of Automotive Shredder Residue (ASR) as special waste in Germany have caused disposal costs to jump 700 % with additional increases projected to result in fees in the $600-$1000 per ton range. While German has mandated the use of recycled materials, France, acting as the project leader on behalf of the European Commission, will develop an overall policy which is likely to result in:

- A comprehensive network of officially approved automotive dismantlers duly appointed by the car manufacturers.

- Reductions in the volume of ASR through mandated closed-loop material recycling.

- A certificate of disposal for the final deregistration of a car, relieving the last owner of the vehicle from payment of a road tax.

A similar trend is beginning to take place in North America. Activity is brisk in the United States with more than 500 proposals introduced in state legislatures during 1991. Although most were rejected, the strong foundation they created resulted in several significant controls being initiated in 1992 and 1993. Representative Toricelli and Senators Lautenberg and Baucus have submitted amendments to the Resource Conservation and Recovery Act and the Solid Waste Act to establish the basic approach. It appears that congressional and administrative directives will include:

- Establishing research priorities, identifying ongoing research and developing strategies for cooperative programs which are to be coordinated by the DOE.

- Establishing a cooperative program between OEMs, dismantlers and the plastics industry to identify obstacles and implement design for disassembly disciplines.

- Identifying toxic and non-recyclable materials and possible substitutes and determining the feasibility of establishing guidelines that would result in the phase out of hazardous and non-recyclable materials.

- Developing more readily recyclable plastics and new ASR recycling technologies.

- Considering economic or market incentives to promote recycling or environmentally sound alternatives for reducing landfills. This may include deposits, disposal fees and rebates, loans or loan guarantees, tax incentives and regulatory restrictions on disposal in landfills.

- Promoting public awareness of auto recycling efforts.

In the U.S., several states have passed strong recycling legislation designed to ease pressure on landfill. Furthermore, the EPA projects that only 2000 of the landfills existing in 1987 will be in operation by 2006. That is down from a high of 17,000 landfills in 1980. However, with 94 % of automobiles currently being recycled and with 75 % (by weight) of those vehicles being recovered, ASR represents less than 1 % to the solid waste problem. Although a contributing factor, the landfill issue will not drive automotive recycling in the short term. ASR represents less than 1 % of the solid waste problem, and landfill expense is minimal when compared with infrastructure development costs.

Compared with other seat cushion materials, polyurethane foam seems to offer the largest number of options in recycling technology. It also offers the widest range and highest percentage of viable outlets for recovered materials.

2.2 RECYCLING HIERARCHY

The recovery, reuse, and recycling of materials in a closed-loop system can be accomplished through (1) product to product recycling or, (2) product cascading recycling, or (3) Product to Energy Conversion recycling. Product to product recycling is a process that reclaims used automotive seat cushions and via mechanical or chemical recycling methods re-introduces the material to the initial production line. The product cascading recycling scheme would reclaim used automotive seat cushions and via mechanical or chemical recycling methods prepare it for a non-automotive product application (e.g., carpet underlayment). Finally the product to energy conversion recycling scheme would reclaim used seat cushions and convert it into useful energy (i.e., electricity, heating) through a mechanical or chemical reaction.

The best recycling method to use must be determined on a product-by-product, material-by-material basis. At the present time the best closed loop recycling scheme for automotive seat cushions is a product cascading recycling method (e.g., seat cushions to carpet underlayment). This requires the least preconditioning of scrap, undergoes environmentally friendly conversion, and its useful life is significantly greater than any other known options. At the present time over 150 million pounds of scrap used for carpet underlayment is imported from Europe and the Pacific Rim. So this market is capable of absorbing 150 million pounds of automotive seating scrap as the dismantling infrastructure develops. In the future the best closed loop recycling scheme for automotive seat

cushions should evolve to a product to product recycling scheme if designs can incorporate quick and efficient disassembly of seat cushions from automotive seats prior to shredding.

2.3 RECYCABILITY OF MATERIALS USED FOR SEAT CUSHION

The three primary materials used for seat cushions are: polyurethane foam, rubberized hair, and polyester. Table 1 provides a competitive evaluation of overall recycling capability for the three materials considered for seat cushions. The majority of automotive seat cushions utilize polyurethane foam since it can easily be tailored to a range of shapes and densities and hardness that provide vehicle owners with outstanding ergonomic comfort and support. Polyurethane foam offers high-performance, light-weight cushioning, and gives the designers the ability to economically create the surface contours of today's revolutionary seating designs.

	Polyurethane	Rubberized Hair	Polyester
Number and types of Recycling Technologies	Mechanical 3 Chemical 3	Mechanical 1	Mechanical 1 Chemical 2
Mechanical Recycling Technologies	**Rebonding** 100 % Usage New Applications **Compression Molding** 100 % Usage Original and new Applications **Powdering** 6% - 40 % Usage Original and New Applications	**Fiber Extraction** 30% Usage Original Applications	**Melt & Extrusion** 0% - 100 % Usage Original Applications
Chemical Recycling Technologies	**Glycolysis to "Polyol & Amine"** 10% - 100 % Usage **Hydrolysis to "Polyol & Amine"** 10% - 100 % Usage Original and New Applications **Aminolysis to "Polyol & Amine"** 15 % Usage Original Applications		**Methanolysis to Original Monomers** 10 % Usage Original Applications **Glycolysis to Intermediate** 10 % Usage Original Applications

Table 1: Recyclability Comparison of materials considered for seat cushions

2.4 FOAMING PROCESS DEVELOPMENT

Polyurethane foam is characterized by it's low density, good thermal and electrical insulation, high resistance to most chemicals and ability to take different colors and opacities. Polyurethane can be easily manufactured into complicated shapes and with little

need for further processing or surface treatment. The basic manufacturing processes for polyurethane foam are extrusion, molding, casting and forming of sheet. The majority of automotive seats are manufactured using an injection molding process. The molded foam process is an environmentally friendly process that produces polyurethane foam seat cushions with CFCs or any other ozone depleting substances. Water is used as the blowing agent in the molding process, so there is no hazard to the ozone in the production and use of molded polyurethane foam. In the molding process recovered solid materials can be incorporated into a reacting mixture, such as polyurethane foam, via conventional preblending techniques. Normally solids are blended into the resin component before being mixed with the isocyanate to form the polyurethane foam.

One of the problems encountered in this process is that there is a large increase in blend viscosity as the amount of solid material is increased. Once blends become too high a viscosity, they cannot be satisfactorily metered and mixed. Preblending of the solids also requires that they are properly dispersed or they may fall out of suspension, fouling the equipment. Also, it is extremely difficult to obtain complete wetting of the particles by the reacting polyurethane mixture. In some cases, particle agglomeration will take place and result in non-homogeneous structure and non-uniform physical properties.

Many efforts are currently underway to overcome these problems by introducing additives into the reaction mixture through specially designed mixing heads. However, only relatively low levels of solids can be incorporated in this manner since the reacting chemicals are increasing in viscosity very rapidly as they change from liquid to polyurethane foam.

Further technology needs to be developed that would overcome these deficiencies and allow high levels of solid materials to be incorporated homogeneously into a foamed polymer matrix. This polymer matrix would include recycled polyurethane products (foams, RIM) and other post-consumer polymers (i.e., reground tires), with a large range of filler particle sizes. The practical solid particle size is governed by the ability of the foam structure to accommodate the particles without rupturing the cell structure.

The incorporation of recovered solid materials as additives in the foaming process can greatly influence color, flexibility, rigidity, flame resistance, weathering resistance and processability. The effects on seating comfort and ergonomic correct support must be taken into consideration when selecting additives for seat cushions.

2.5 MATERIAL SELECTION AND PREPARATION

Certain thermoplastics materials (i.e. polyurethane) can be recycled if contamination of the plastic is avoided prior to reuse. Automotive Shredder Residue (ASR) consists of a non-homogeneous mixture of glass, rust, plastics, rubber, seat covers, polyurethane foam, and other materials. All of this mixture is contaminated with other automotive fluids such as brake fluid, transmission oil, motor oil, and dirt.

Since clean polyurethane foam is readily recycled or reusable, it's possible to reuse the polyurethane portion of the ASR, if it can be cleaned up. Currently, however, all ASR ends up in landfill sites. Significant quantities of polyurethane foam are contained in this ASR, but separation post-facto is very difficult and expensive at this time.

Initial indications from an on-going study shows encouraging results for the use of recovered thermoplastics and thermosets (RIM fascia) and polyurethane foam materials in seat cushions. Both painted and unpainted fascia, tire, and polyurethane foam scrap from various sources have been successfully incorporated as additives in the foaming process. A short term target would be to develop a seat cushion that utilizes up to ten parts per hundred of recovered material.

It has been possible to use decontaminated (washed) ASR, derived-polyurethane foam scrap in new applications such as instrument panels, and carpet underlayment. The performance of rebonded ASR carpet underlayment has been equivalent to normal in-process scrap rebond. The only current problem is the removal of a mildly musty odor. It is expected that this problem will be resolved in the near future. Then, it will only remain to determine how to economically separate the balance of the polyurethane from the balance of the ASR mixture, or better still, recover the foam prior to shredding. The design of seat cushions for disassembly and therefore economically recovering the foam prior to shredding is discussed in the next section.

3. DESIGN FOR DISASSEMBLY

Polyurethane foam has the flexibility to conform to many different assembly and attachment methods. Most current seat systems have cushions with molded-in (encapsulated) seat frame and border wires. These seat systems are very difficult to disassemble and require a greater deal of labor to strip the foam away from the seat frame. The optimal seat design

for disassembly would consist of a cushion that sits on a seat frame or support and has no cover attachments. The seat cover would be bonded to the seat cushion and frame. This design would allow the quick disassembly of seat cushions to aid the recycling effort. An intermediate solution would be a seat system where the cushion would sit on a frame or support and have Velcro and/or surface wire cover attachments. Below is a design evaluation for each set system component:

Seat Covers: are slipped onto the seat frame and cushion and sewed in place. A few of the current models in production utilize a zipper for easy replacement. The optimal method for disassembly would be to bond cloth as well as leather seats to the cushion and set frame.

Seat Frame: are constructed of metal and wire and support the occupants weight. In many current production seats systems the cushion has a molded in frame. This requires that the cushion is stripped from the seat frame. This technique makes is difficult to recovery the polyurethane foam and the metal since it is difficult to strip the foam from the seat. The recommendation is to design a standardized seat frame that can accommodate a series of seat cushions. The recommended fastening technique for the seat cushion to frame should either be a snap lock or Velcro. Complete seat frames should be recovered and reused by OEMs if possible.

Seat Cushion: The seat cushion should be molded to meet the customer support needs as well to enable its disassembly. The seat cushion should provide easy removal of lumbar support mechanisms through the use of pockets and sleeves rather than encapsulation of these features. A good example of this is football pants, that provide pockets or sleeves for different size pads and body parts. Seat cushions should also clearly displayed the materials used for its construction and disassembly steps.

Seat Fasteners: The seat system should utilize a standardized fastening technique to attach the seat to the car's floorpan. The fastening technique should become an industry standard to enable quick disassembly.

Designers must develop a plan for the reuse of seat materials post-consumer to enable recycling of the product. This may require the formation of strategic alliances with other industries for the eventual product cascading scheme to be properly accomplished. The

designers must also strive to reduce or eliminate all attaching components that would make seat disassembly harder.

4. DESIGN PROCESS

The process utilized in the development and design of the lumbar support system included:

- Requirements definition (section 4.)
- Concept generation and selection (section 5.)
- Final concept definition (section 6.)
- Design and application development (section 7.)

While each of these efforts are critical to the overall success of the project, the requirements definition process was the most important of the steps. Therefore a considerable amount of time was spent researching the issues at hand, listening to the customer to better define the product's requirements.

4.1 REQUIREMENT DEFINITION

In order to clearly define the requirements for the seat product, the following steps were followed:

- Establish a mission statement for the project
- Define any assumptions or preconceptions for the project
- Search literature and expert sources in order to determine the latest knowledge on the subject
- Investigate existing technology applicable to the area of study
- Understand the physiological aspects (inherent requirements) for seat products
- Listen to the "Voice of the Customer" regarding product requirements.
- Define product requirements based on the information gathered

The methods involved with these steps and the results for the lumbar support are discussed below.

4.2 MISSION AND BASIC ASSUMPTIONS

Establishment of the mission statement for the project allowed focused the effort on certain aspects of automobile seating and the issues of greatest importance. While the mission was meant to be dynamic, it provided a steadying force during the many phases of the product development cycle. The mission statement was

" The goal is to develop an improved lumbar support system for automotive seats. It will provide ergonomically-correct support for the 95th percentile person. It will be simple, manufacturable, low cost, reliable and maintainable."

With this mission statement, the project focus was narrowed to lumbar systems only.

Basic assumptions made, were based on requirements from General Motors; practical issues related to the fabrication and assembly of seats; and the concept of comfort for seating. The assumptions for the project were:

- To develop and improve the process of designing seats along with producing a better design
- Consider alternative seat styles
- The lumbar support device will fit within the constraints of an "adjustable lumbar system" currently in production
- "Ergonomics" will be defined as "comfort and support"

4.3 LITERATURE SEARCH

To build a base of knowledge about existing seating technology and in particular lumbar support systems, an intensive literature research was conducted. Through MIT's computerized literature search service nine national and international data bases were surveyed. The data bases were as follows:

AIAA	American Institute for Aeronautics and Astronautics
EMBASE	Elsevier Science Publishers
COMPENDEX	Engineering Information Inc.
EXCERPTA MEDICA	Elsevier Science Publishers
NTIS	National Technical Information Service
SUPERTECH	Bowker, N.Y.
MED LINE	National Institute of Medical Health
United States Patents	IFI/Plenum Data Corporation
WORLD PATENTS	Derwent Publisher Ltd.

From this search 90 articles and 20 patents related to the car seating problem were selected. These included papers concerning medical issues, car seat design and patents related to seats.

The medical papers provided an understanding of the physiological aspects involved with seating. Based on this research, the orthopedic requirements for correct seating were defined and further discussed in Section 4.5.

The car seating problem is not very well published in the literature. Only a very few papers were found specially concerning car seating problems. None of these papers found gave specific information on seat design concepts, though they provided background regarding the complexity of the seating problem, especially in cars.

There are many patents for seating concepts on file. However, none of the patents found in the patent search were directly applicable to the lumbar support problem. From products found in the marketplace, several patents are pending for lumbar support systems designed for the "bad-back" market.

A further source of information was Dr. Robert Hubbard from the Department of Biomechanics of the Michigan State University. He is an expert in the seating areas and the conversation with him provided insight into the details of seating, see Appendix 1.

4.4 EXISTING TECHNOLOGY

Benchmarking of Seating Products

There are many varieties of seating enhancements products on the market to meet the needs of customers with bad backs. These take the form of foam cushions, air cushions and bladder support systems. Each met a different market need, such as basic lumbar support or massage. A key point of differentiation among the products was the adaptability of the product to different customer preferences and curvatures. Most effective in this area was the air cushion product which provided a semi-active support for the customer. This allowed the cushion to conform to curvature of the customer, providing superior level of comfort versus a standard chair.

While some of the products investigated provided a direct solution to the problem of developing a lumbar support system for an automobile, they did provide concepts for possible application and most importantly, a perspective of customers needs. Therefore, the challenge is to meet these customer needs as applied to a car seat.

Implemented Lumbar Support Systems

There are different lumbar support system types currently implemented in car seats or separately available in the market. These systems can be divided into three categories:

- Cushion Systems
- Mechanical Systems
- Bladder Systems

The cushion system type are add-ons to regular car seats. They basically add extra compliance to the seat, but do not permanently conform to the body. Some utilize a bladder system to provide support, while others are totally passive systems of foam.

There are two mechanical systems, the paddle type and the grid type. The paddle type, as implemented in the Pontiac Grand Am seat, uses a stiff sheet metal plate which rotates around a hinge point. It pushes from the back side against the padding material of the seat-back to partly deform the back surface.

The grid type system, as implemented in GM's Allante model, referred to as the Schukra System, uses a flexible metal grid which is bent by an electro-mechanical gear mechanism, pulling the upper and lower grid ends together. With a vertically varying stiffness of the grid, this results in a certain curvature which can be adjusted to the individual's preference. The entire grid system can be adjusted in its vertical location to fit different body sizes. The entire system consists of about 75 parts.

The bladder type systems, as implemented in GM and Mercedes Benz vehicles, uses three to four individually inflatable bladders to provide a certain shape. The bladders can be controlled separately to adjust for individual preferences. This system consists of about 75 individual parts.

Problems with the existing concepts

Though the Schukra system provides good lumbar support, none of the existing systems meets the physiological and the individual customer comfort preferences at the same time, as was experienced during the clinic.

The passive cushion type do not provide an "ideal" curvature and in most of the cases can not be positioned where needed. Therefore it can not provide sufficient and orthpedically correct lumbar support.

The same problem appears with the paddle-type system which is not able to provide the desired curvature. Furthermore it creates on significant pressure point which leads to uncomfortable seating and can cause serious injuries in case of an impact.

The Schukra system is considered to be the top system currently on the market. It provides good lumbar support, but often does not conform to individual body shape (but does provide the orthopedically correct curvature). The complex two dimensional curvature in the vertical and in the horizontal required for individual comfort can not be provided from this system.

As mentioned above, the bladder type systems use three to four individual bladders. the problem with the bladders is that they can not create a continuous curvature to support the human back over a large area. Nor can they properly distribute the weight of the body. Instead, the bladders create pressure points across the back that hinder proper blood

circulation and results in uncomfortable seating after a short period of time. Because of this issue, most customers totally deflate the bladders after a few minutes of use. A potential solution is to reduce the size of bladder and increase the number of bladders. But this results in even more control elements, making proper adjustment for the customer tedious. The bladder adjustments are also affected by the poor responsiveness of the air system.

4.5 PHYSIOLOGICAL AND BIOMECHANICAL CONSIDERATIONS

Discomfort in seating can be attributed to two aspects: one is psychological and the other is physiological. How the seat looks will mostly affect one's psychology, but physiological reasons cause true physical pains.

Back problems are the second most common cause of work loss in the U.S., second only to the common cold. Prolonged unsupported sitting tends to be detrimental to the back.

The key to reducing back problems is well-designed seats. A good seat should support the natural curves of the back and distributes the body's weight evenly at all the time supporting the movement of the body in its ever-shifting postures.

The spine of human beings is an unstable column. The column consists of bony vertebrae cushioned by fibrous discs. It is supported by muscles and ligaments in its three natural curves (Figure 1): the cervical curve which refers to the seven vertebrae on the top; the thoracic curve which refers to the next twelve vertebrae and the lumbar curve which refers to the five vertebrae below the thoracic curve.

There are three major factors that may cause discomfort in sitting postures. The first is the unevenly distributed pressure exerted on the intervertebral discs (Figure 2). This may cause slipped discs. The physiologically correct situation should be such that the pressure on the individual intervertebral discs is uniform (Figure 3).

The second factor is the increased pressure on the intervertebral discs. When people are sitting upright without back support, there is about 35% higher pressure on the intervertebral discs compared with standing. Increased pressure on the intervertebral discs can speed up the natural deterioration process and cause discomfort. Sustained increased pressure on the intervertebral discs can lead to painful problems such as a herniated disc, where the pressure ruptures the disc wall allowing the disc fluid to bulge out and pinch the

nerves in the spinal cord. In the lower back, the nerve that is likely to be affected is the sciatic nerve, a pinched sciatic nerve causes pain to radiate to the back and legs.

The third factor is muscle strains. While the intervertebral discs cushion the movements of the vertebrae, the muscle system supports the spine and its movement. Muscles have to work harder to support the spine when one is sitting in an upright or forward-leaning position than when one is standing. However, strained muscles may affect the central nervous system which is located in the spinal cord and controls all the bodily functions such as respiration, circulation, heartbeat, fatigue, concentration, etc. The central nervous system can only fully function when the muscles of the spinal column are not stressed by unnecessary strains due to poor posture. The ideal situation should allow as much of the body's musculature to relax as possible, and takes advantage of the body's own ability to support itself. Therefore a continuous ergonomically optimal adjustment of the seatback curvature to fit the anatomical curvature of the spinal column and individual daily fatigue is absolutely necessary.

Solutions include efforts to maintain the natural curves of the spine by providing lumbar support, and transferring some of the weight of the upper part of the body to the backrest. This noticeably reduces the physical load on the intervertebral discs as well as the static strain of the back muscles. Well-designed seating will offer ways that the body can transfer body weight off the back, reducing the amount of intervertebral disc pressure and giving the muscles and ligaments some rest.

Ergonomically Correct Lordotic Support

These considerations lead to the medically recommended three-fold criteria for an ergonomically correct lordotic support:

(i) Support of the pelvis to prevent the pelvis from sliding backward;
(ii) Support of individual vertebra to distribute pressure on the intervertebral discs uniform;
(iii) Support of the lower thorax, thus transferring a portion of the weight of the upper part of the body to the backrest.

These three-fold criteria are illustrated in the figure 4.

In addition, a good lordotic support must not be firmly secured to the structure of the seat or the back support, but rather have a floating attachment in order to accommodate the swaying and movements of the driver in a car.

It should also be noted that the shape of the spine can be very different from one individual to another, and that an individual's spine shape also changes over time. This requires that the supporting curve be adaptable to individual natural spinal orientation.

4.6 VIBRATIONAL EFFECTS ON HUMANS

Vibrations of the vehicle/occupant interface such as hand-to-steering, feet-to-floor, and body-to-seat, need to be measured and evaluated in order to design optimal vehicles with respect to comfort. The first is to identify harmful or irritating vibrations. The chart below (table 2) provides a range of symptoms at various vibrating frequencies.

Symptoms	Frequency (Hz)
General feeling of discomfort	4 - 9
Head symptoms	13 - 20
Lower jaw symptoms	6 - 8
Influence on speech	13 - 20
Lump in Throat	12 - 16
Chest pains	5 - 7
Abdominal pains	4 - 10
Urge to urinate	10 - 18
Increased Muscle Tone	13 - 20
Influence on breathing movements	4 - 8
Muscle Contractions	4 - 9
Motion Sickness	.1 - 1

Table 2. Vibrational Effects on Humans

4.7 DRIVING FATIGUE PARAMETERS

The strength requirements which must be met by the seats in a collision pertain to the seat cushion and backrest, the head restraints, the seat adjustment mechanism and the seat anchors. One component of active safety is seating comfort. Seats must be designed such

that vehicle occupants with different body dimensions do not suffer from driving fatigue. The key parameters used to prevent driving fatigue are:

- Support of individual body areas (distribution of pressure)
- Lateral support when cornering
- Seating ambience,
- Freedom of movement so that an occupant may change his sitting position without readjusting the seat.
- Vibrational and damping characteristics (matching of natural frequency with the excitation frequency band)
- Adjustability of seat cushion, back-rest and head restraints.

The above parameters are affected by (1) Distribution of the spring rates of individual cushioned zones, (2) Overall spring rate and damping capacity, of the seat cushion in particular, (3) Thermal conductivity and moisture absorption capacity of the covers and upholstery, and (4) Operation and range of the seat adjustment mechanisms.

4.8 VOICE OF THE CUSTOMER

An important component of any requirements definition process is direct feedback from the customer. Listening to the "Voice of the Customer" in the Lumbar project was especially critical. Since individual preferences of comfort could not easily be measured, the comments and ratings of a wide range of drivers were necessary to define the direction for the seat design.

During the project, several methods were utilized for obtaining customer feedback:

Customer Comfort Clinic
Interviews with Car Enthusiasts
Benchmarking of non-auto seat products

Each provided information about the needs and desires of the driving public regarding seats and lumbar support specifically. A description of the methods used and results obtained are contained below.

Customer Comfort Clinic

Direct feedback from customers was obtained utilizing the customer comfort clinic format. Four seats supplied by General Motors were used for the test, including:

1) Cutlass Sierra	(hand pump bladder lumbar system)
2) Pontiac Grand Am	(bar lumbar system)
3) Cadillac Allante	(Schukra lumbar support system)
4) Corvette	(Three chamber bladder system)

Customers were asked to complete a question form (appendix 2) to evaluate each of the seats individually on aspects related to the lumbar support and general seat comfort. The order of trail was randomly selected to prevent order differences. Twenty customers, primarily members of the MIT community, took part in the clinic. Of these customers, seventeen submitted completed surveys and were included in the analysis.

Results from the customer clinic reflected the lack of a general definition for "comfort". Each customer had his/her idea of what a good seat should be and how much lumbar support was required. In summary, customers found the Cadillac Allante' seat with the Schukra lumbar support to be superior to the other seats in the test. Even customers who before did not think much about seat comfort felt the Schukra system offered better and more completely adjustable lumbar support. However, the ease of control of the Schukra was a bit of a concern and some customers commented on the noise associated with the system. Appendix 3 summarizes the results of the customer ratings for each of the auto seats.

Additional benefit was obtained from the comments of the customers during the test period. For instance, the need for adjustability in the lumbar support design was captured in comments such as:

> " ...(seats) should be easily adjustable and comfortable for short and long trips"

> " Lumbar support adjustable for height would be good"

The focus on the lumbar region was supported by comments such as:

" Lumbar support is most important to me."

Not all customers were concerned with seating:

" I'm not too particular about seats."

Even these customers, when provided alternatives which were better than previous experiences, seemed to appreciate the superiority of a good lumbar support system. A complete summary of the customer responses from the clinic can be found in Appendix 4.

Interviews with Car Enthusiasts

Another source of customer feedback was from a group of car enthusiasts at MIT who discussed aspects of automobile seating in response to a question posed to them. The MIT electronic mail system "Athena" was utilized for collecting this information. Among the comments of mention from this source of feedback was one concerning the adaptability and customization of car seats:

"If I could afford it, I would have customer seats installed. All the automakers offer only one standard bucket seat, which is supposed to fit everybody."

A complete summary of these results can be found in Appendix 5.

In summary, listening to the voice of the customer provided the team with raw product requirements such as:

- Comfort is an individual thing, the seat must adjust to meet these individual preferences
- The seat should be adaptable to different people and conditions, including changes during longer trips.
- Customers wanted to "feel the change" when controls were used; the lumbar system should provide feedback to the individual when controls are used rather than slow or subtle changes.
- Controls need to be simple to operate, especially for the driver.

- Along with being responsive, the customer seems to desire a system that was noticeable and obvious.

4.9 PRODUCT REQUIREMENTS

Product requirements for the lumbar system are a conglomeration of information obtained during the requirements definition process. Effective requirements are a compromise between each requirement source (physiological needs, customer preference and manufacturer experience). However, the primary driving force behind the drafting of the requirements was the "Voice of the Customer".

Requirements for an improved lumbar support system are divided into three categories:

- Musts - requirements which must be met by the improved product.
- Linear Requirements - requirements which are the "the more the better" in the eyes of the customer
- Exciter Attributes - product attributes which add to the appeal of the product for the customer, but do not detract from the product's appeal if they are absent

Musts for the lumbar system were determined to be:

- System must have an adjustable curvature to conform to individual shapes.
- System must meet the natural curvature of the spine (requires adjustability to enable correct curvature for all people)
- System must provide for a padded support which conforms to provide individual comfort.
- System must distribute the weight evenly across the back to reduce muscle fatigue surrounded with uneven support.

Linear requirements for the system include:

- System should provide good ventilation to the lumbar area.
- System should allow adaptability to frequent position changes by the seat occupant, especially during long drives, or possibly concepts such as "intelligent seating" which change over time based on feedback.
- System should be easy to adjust and have a simple control system.
- System should be responsive to user controls.

Finally, possible exciters could include:

- Heat
- Massage
- Blowing air
- Stimulation cells on support surface
- Beads

While these product requirements are not all encompassing, they did provide a solid basis on which to judge product concepts brought forward.

5. CONCEPT GENERATION

Based upon the product requirements developed through a literature search and 'voice of the customer' data, the next step was to generation of concepts. Although the goal was to develop designs that would meet as many of the requirements as possible, it became evident that some of the product requirements were mutually exclusive. For example, in order to provide a correct orthopedic curvature for different individuals, complex controls were often required. Compromises were made in this regard, and designs were generated that provided the best solution for the problem at hand. The concepts are briefly outlined below.

The 'Semi-Active Cushion':

In order to provide ideas for design concepts, various products were purchased that are available for use by people with back difficulties. One of these was a back cushion that consisted of a rectangular piece of foam which was covered by a nylon material. The covering provided an airtight seal, and a valve was attached to the product which could be opened and closed by the user. Opening the valve when the back was pressed against the cushion allowed air to escape from the cushion, thus providing a contour which would conform to the shape of the individual. The desired shape could then be maintained by closing the valve. Removing pressure from the cushion and opening the valve would allow the foam inside to expand and return the cushion to its original, undeformed position.

This proposed design was essentially the implementation of this device in an automobile seat. In the concept, the semi-active cushion described above was placed within the back

of the seat, and a motor was used to allow adjustment of the vertical location of the cushion.

Modified Schukra A:

This design was an attempt to improve upon the existing Schukra device. The idea was to provide a more individually customized curvature using the same metal grid of the Schukra. Different parts of the system could be individually adjusted, although the details of the mechanical means of accomplishing the adjustments were not yet developed.

The 'Structural Backbone' Concept:

This concept was unique from all the others in that it was a concept for an entire automobile seat rather than one specifically for the lumbar region. It implemented a structural backbone upon which modular supports were placed and could be individually adjusted. The design also called for the semi-active cushion described previously to be utilized. However, the cushion was to be given an orthopedic shape constructed out of two different types of foam. In addition, message and temperature control units were provided.

The Fluid-Filled Bladder:

This concept was similar to the bladder-type devices found in current automobile seats with one noticeable exception. Instead of using air as the working fluid, the idea was to introduce another fluid into the bladder with a higher viscosity than air. The purpose of this was to allow for a slower time-varying configuration in response to movement from the seat occupant.

Modified Schukra B:

This design parallels the Modified Schukra A concept. In this case, the metal grid was placed in front of cylinders of oval cross-section. The cylinders could be rotated and moved in the vertical direction in order to provide a wide range of curvatures.

The Bladder Matrix:

Another idea based upon current bladder technology, the bladder matrix concept implemented two layers of bladders. One layer had three rectangular sections oriented in the vertical direction while the other had three rectangular sections oriented in the horizontal

direction. Each individual section could be individually inflated or deflated to provide the desired contour. Temperature control and message units were also included.

Flexible Columns:

The idea behind this concept was to use two flexible columns with additional flexible members placed between them. The columns could be bent and twisted to provide different shapes for the seat back. The details of this design had yet to be worked out at the time of its presentation to the group.

Additional pictures and descriptions of all of the above concepts (except for the semi-active cushion) can be found in appendix 6.

6. FINAL CONCEPT DEFINITION

Following the concept generation phase, the task of rating and ranking the different concepts was undertook. A decision matrix containing the product requirements was used, with each requirement given a weighting of 1, 2, or 3. Because of the positive feedback received about the Schukra, it was chosen as the reference design. In addition to the group's concepts, an Oldsmobile touring sedan seat containing bladders was included for the sake of comparison.

The results of the rating and ranking procedure are shown in Figure 7. It was interesting to note that of all the concepts, only one scored above the Schukra (however, all of the group's concepts scored above the Oldsmobile bladder system). Ideas were developed to address specific deficiencies of each concept and, where possible, different concepts were combined to produce new designs which would satisfy a larger number of the product requirements.

Eventually, it was decided that the semi-active cushion concept was the most promising design and the one which should be further developed. At this stage the concept consisted of a composite piece of foam with an orthopedic shape and the airtight covering and valve. The cushion was to be designed such that it could be integrated into currently existing automobile seats.

To further investigate the design, various prototypes were built. These prototypes were needed to study the effectiveness of differently shaped cushions as well as to test the operation of the unit as a whole. Information gathered from the prototypes changed some of the ideas about the concept, and indeed the design itself. Further prototypes were built and more was learned about the needed shape, which varied with each individual and thus required a need for customization. Finally, after numerous iterations, a final design concept was selected for the CushAire lumbar support.

7. DESIGN OF FINAL CONCEPT: THE CUSHAIRE SYSTEM

The CushAire system is a shaped cushion which in its unactuated position is fully inflated. The cushion is a composite of two layers of different density foam. The multilayer composite foam structure provides support for the occupant as well as a proper orthopedic contour. The block shaped, rear layer of dense foam provides support for the customer while the contoured front layer of less dense foam provides proper orthopedic support for the occupant. The composite cushion is surrounded by an airtight envelope through which protrudes a vent valve. A vent hose is routed to a normally closed air solenoid, which when actuated by the user will allow air to vent into or out of the CushAire system (Figure 8).

Pressure applied to the cushion by any part of the seat occupant's anatomy while the valve is depressed will cause the contained air to vent and the cushion to conform to the shape of the occupant. Release of the button will cause the envelope to seal and the cushion to retain that shape while providing uniform support to the lower lumbar region.

To refill the cushion, the occupant needs merely to release the body pressure on the cushion and again push the valve button. The foam inside will cause the cushion to refill, automatically to its original position.

Family of Products

The CushAire family of products consist of 9 different models. (Figure 9) The two parameters which the consumer chooses is the shape of the contour and the firmness of the CushAire cushion.

The first parameter that can be varied is the shape of the contour. The three different contours available to a user are high, middle, and low curvature. Each of these three variations has a common horizontal profile but varies the location of the high point of the contour in the vertical axis. This allows the product to provide different contours to satisfy the needs of a wide range of spinal structures. Providing an orthopedically correct contour will reduce the level of discomfort of individuals with chronic back problems during long trips.

The second parameter that can be varied is the overall firmness of the CushAire cushion. The three levels of firmness provided are soft, medium, and hard. Each of these firmness levels provides a different level of support to meet differences in individual preferences.

Design for Manufacturability/Assembly

A great deal of effort was spent on developing a concept which could be easily adapted to the needs of the customers while maintaining a high level of manufacturability. The design selected promotes aspects of the design which complement the manufacturing process associated with its construction. The firmness variable (soft, medium, hard) translates into a material change on the production floor, while the contour selection (high, middle, low) utilizes a modular design to ensure manufacturability. Care was taken to ensure that other critical and costly components remained fixed and were not crucial to the marketing success of the product.

Figure 10 shows that the major areas of product variation are with the rear and front layers of foam. In addition the effect on the manufacturing process is isolated to two steps (cut contour, and assemble and bond foams together). The integration of the marketing plan with the manufacturing process provides the customer increased variety at a low cost.

Other significant design for manufacturing criteria are shown in Figure 11. As outlined earlier the primary goal was to provide comfort to the customer while utilizing a simple design theme.

Overall Seating System

The vision for the CushAire product is that it would be housed in a separate lumbar pouch in the lower part of the seat. In this manner the customer could easily interchange cushions when different passengers traveled with them. The separate pouch would also allow the

cushion to be unrestricted in movement while filling and deflating. The vision is of a customer being fitted for his CushAire product while selecting his vehicle, merely as he would select any other option available for his vehicle. The order to the factory would include his individual preferences as well physiological fit for his CushAire product. The cushion would be delivered to the dealership for final preparation and installation. In addition the dealership would be equipped to retrofit vehicles of other customers who desired this product.

The CushAire system relatively low price allows its introduction in economy as well as luxury vehicles. The modular design of the product allows it to be easily retrofitted into most current production seats. The ability to offer an advanced lumbar support system throughout the GM vehicle line-up while achieving massive economies of scale will provide GM with a competitive advantage. In addition the ability to vertically integrated forward into the dealership by providing a new level of customization will provide GM will valuable returns on its investment.

Future Option

There are many features which need further investigation and have been outlined below. Many of these features can be viewed as product exciters which would enhance the level of customer satisfaction among users.

- Provide a heating option for the CushAire system for cold winter days and long trips

- Provide a series of bumps on the surface of the cushion to increase ventilation, provide passive massage, and allow unobstructed movement by the occupant.

- Development of an electrically adjustable firmness control by installing electrical heating elements in the dense foam to alter the foam's firmness characteristics

- Retrofit of the CushAire system so that it can be offered as an option with the existing Schukra system

- Provide a simple ventilation bladder, which gradually dissipates air to the lumbar region, to be installed in the front of the CushAire system to provide added ventilation to the system

- Develop an electronic control module for the lumbar support mechanism to allow the system to provide time-varying stimulation and adjustment of the lumbar support system.

8. CONCLUSIONS

The following is a list of the important lessons that were learned during the development of CushAire system:

- Defining "comfort" in the development of CushAire has been most important. The metrics of human physiological and psychological concepts of comfort are interrelated and sometimes opposing to each other.

- Comfort has only been vaguely defined. It has been much more difficult to set up the "Comfort Requirement" in quantitative terms than had been expected. Comfort is mostly viewed as art instead of science.

- In the concept evolution/application process, seeking simplicity may often prove to be more effective in contrast to seeking to be revolutionary.

- The project turned out to be harder than first thought, because of the lack of precise information on the product requirement.

Based upon proven technologies, the current product is simple in design and structure, effective in function, inexpensive to manufacture and also provides options for customization. In the designing process, a compromise was made between physiological/biomechanical needs and individual preferences of comfort. As a result, customer satisfaction and loyalty could become guaranteed. Applications to a wide range of GM products are strongly recommended.

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FIGURES

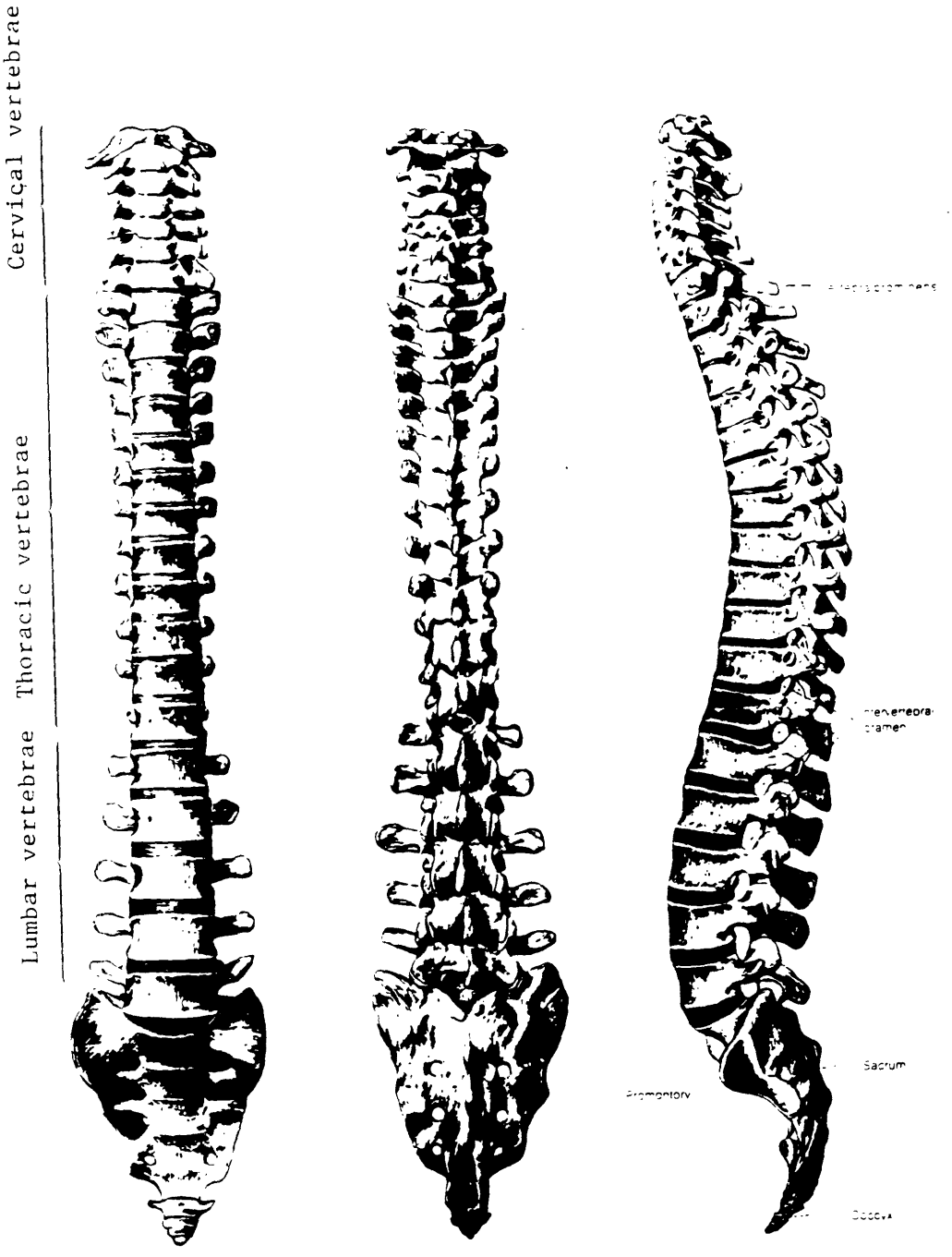
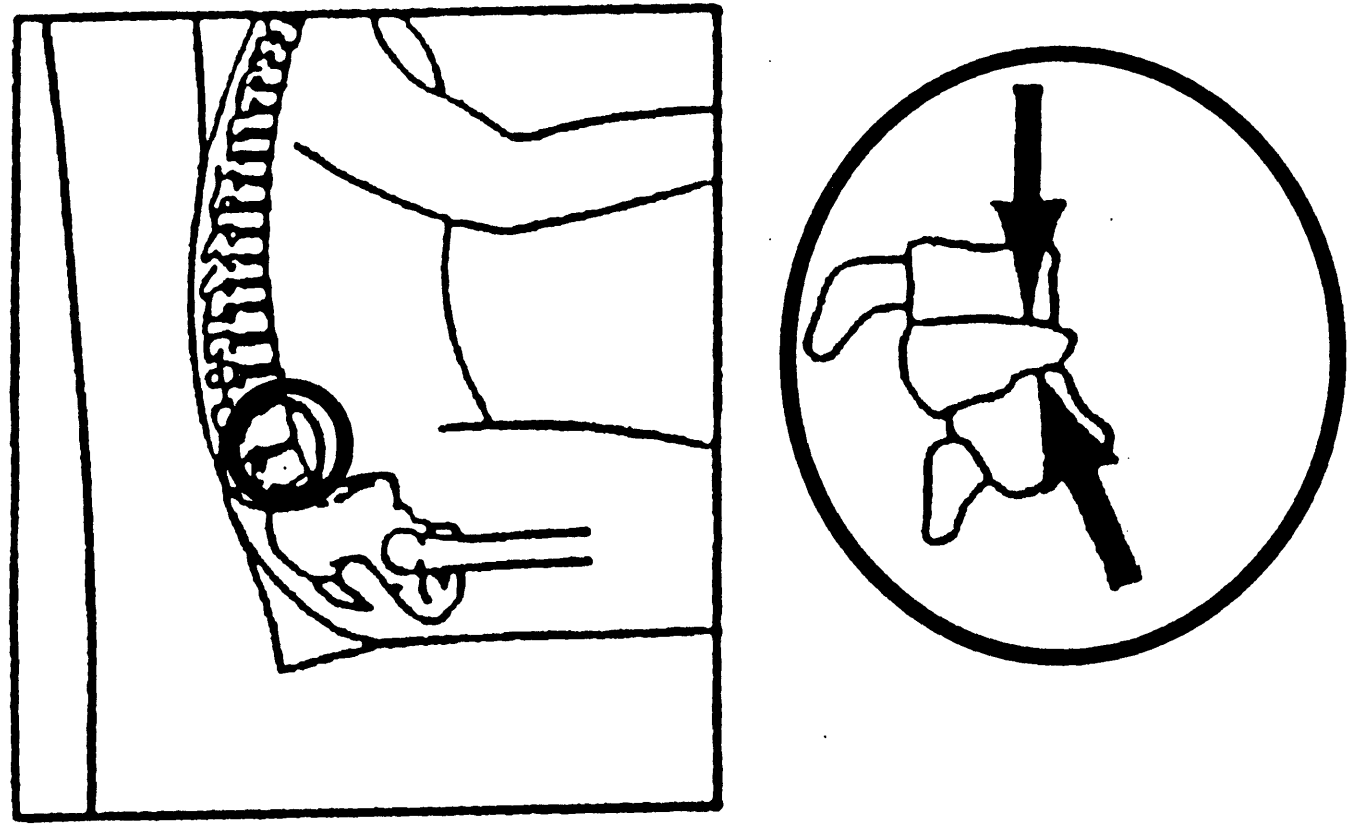


Figure 1 : Structure of human's spinal column: Rear view (left), front view (middle) and side view (right).

Figure 2

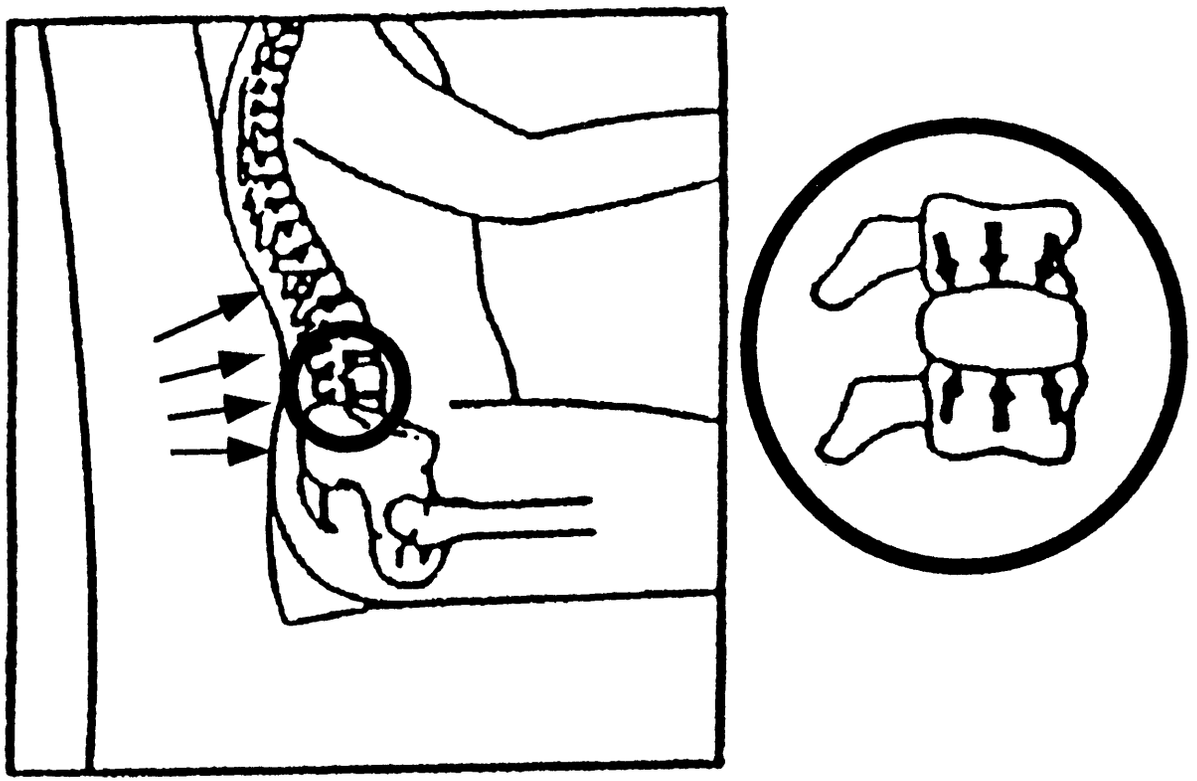
Spinal Discomfort



CushAire Lumbar Support

Figure 3

Lumbar Comfort



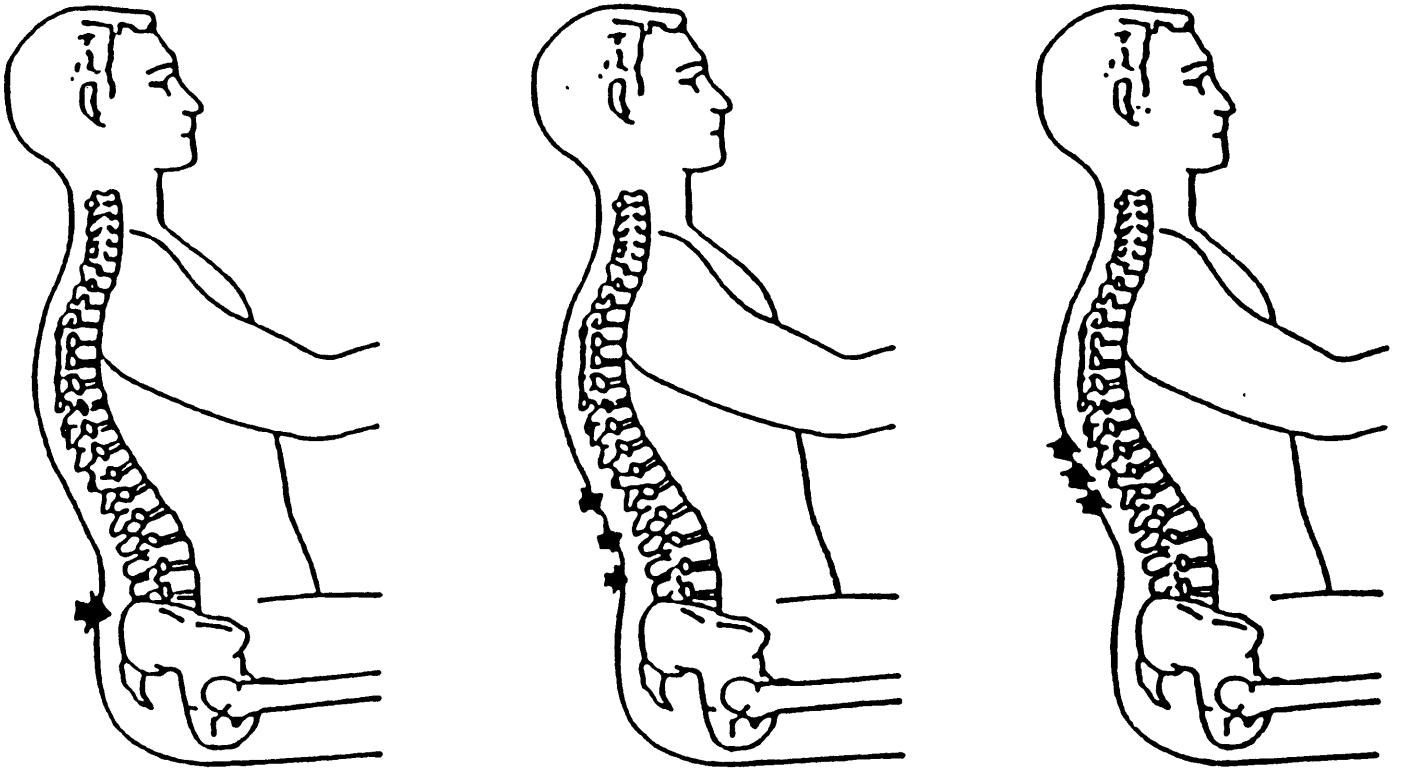


Figure 4 : Medically recommended three-fold criteria for lordotic support: Support of the pelvis (left); Support of individual vertebra (middle) and support of the lower thorax (right).

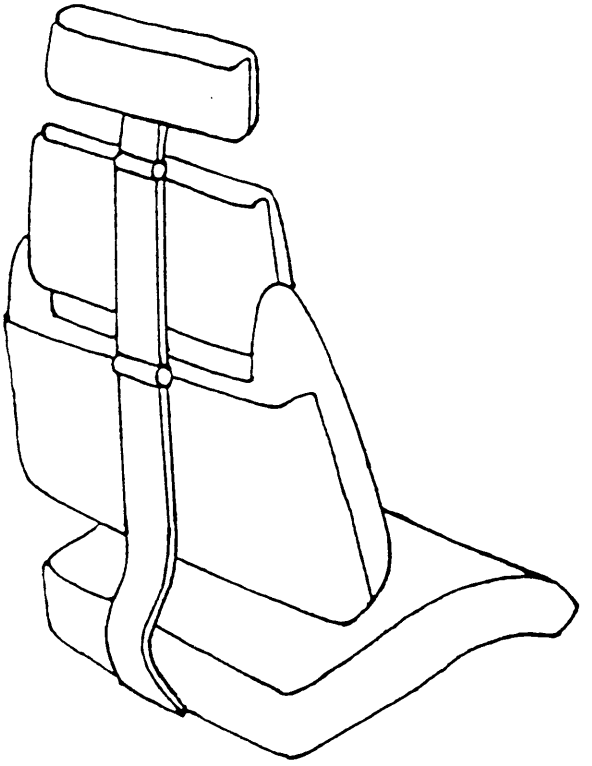


Figure 5

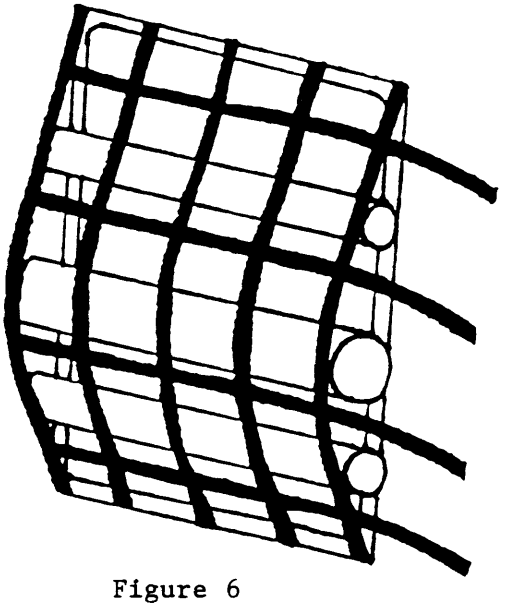


Figure 6

Figure 7

Product Requirement (weight)	Schukra	Olds Bladder System	Semi-Active Cushion	Modified Schukra A	Structural Backbone Concept	Fluid-Filled Bladder	Modified Schukra B	Bladder Matrix Concept	Flexible Columns
Compatable with existing seats (2)	0 0	0 0	0 0	0 0	- -	- -	0 0	- -	- -
Can be implemented in a reasonable amount of time (2)	0 0	0 0	+ +	- -	- -	0 0	0 0	- -	- -
Small number of parts (2)	0 0	- -	+ +	- -	0 0	+ +	- -	- -	- -
Low manufacturing complexity for individual parts (3)	0 0 0	- - -	+ + +	0 0 0	- - -	- - -	- - -	- - -	- - -
Reliable design (3)	0 0 0	- - -	- - -	- - -	- - -	0 0 0	0 0 0	0 0 0	0 0 0
Massage (1)	0	0	0	0	+	0	0	+	0
Time varying configuration (1)	0	0	0	0	0	0	0	0	0
Temperature control (1)	0	0	0	0	+	0	0	+	0
Lateral support (2)	0 0	+ +	0 0	0 0	0 0	0 0	+ +	+ +	+ +
Non-confining (2)	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Compatable with proper pelvic orientation (3)	0 0 0	- - -	- - -	+ + +	0 0 0	- - -	0 0 0	- - -	0 0 0
Helps support body wieght (2)	0 0	- -	- -	0 0	0 0	- -	+ +	0 0	0 0
Desirable firmness (2)	0 0	0 0	+ +	- -	+ +	+ +	- -	+ +	+ +
Correct orthopedic contour (2)	0 0	0 0	+ +	0 0	+ +	+ +	- -	+ +	+ +
Adjustable vertical location (1)	0	0	0	0	0	-	0	-	0
Adjustable width (1)	0	+ +	0	0	0	0	0	+	0
Conforms to body contour (3)	0 0 0	+ + +	+ + +	0 0 0	+ + +	+ + +	- - -	0 0 0	0 0 0
Easy-to-use controls (3)	0 0 0	- - -	0 0 0	- - -	- - -	0 0 0	- - -	- - -	- - -
Responsive controls (2)	0 0	- -	- -	0 0	- -	- -	0 0	- -	- -
Total +'s	0	5	14	3	9	9	4	9	6
Total 0's	38	14	14	23	14	16	19	11	18
Total -'s	0	18	10	12	15	13	15	18	14
Net score	0	-13	4	-9	-6	-4	-11	-9	-8
Rank	N/A	N/A	1	5	3	2	7	5	4

Figure 8

CushAire Product

(Exploded View)

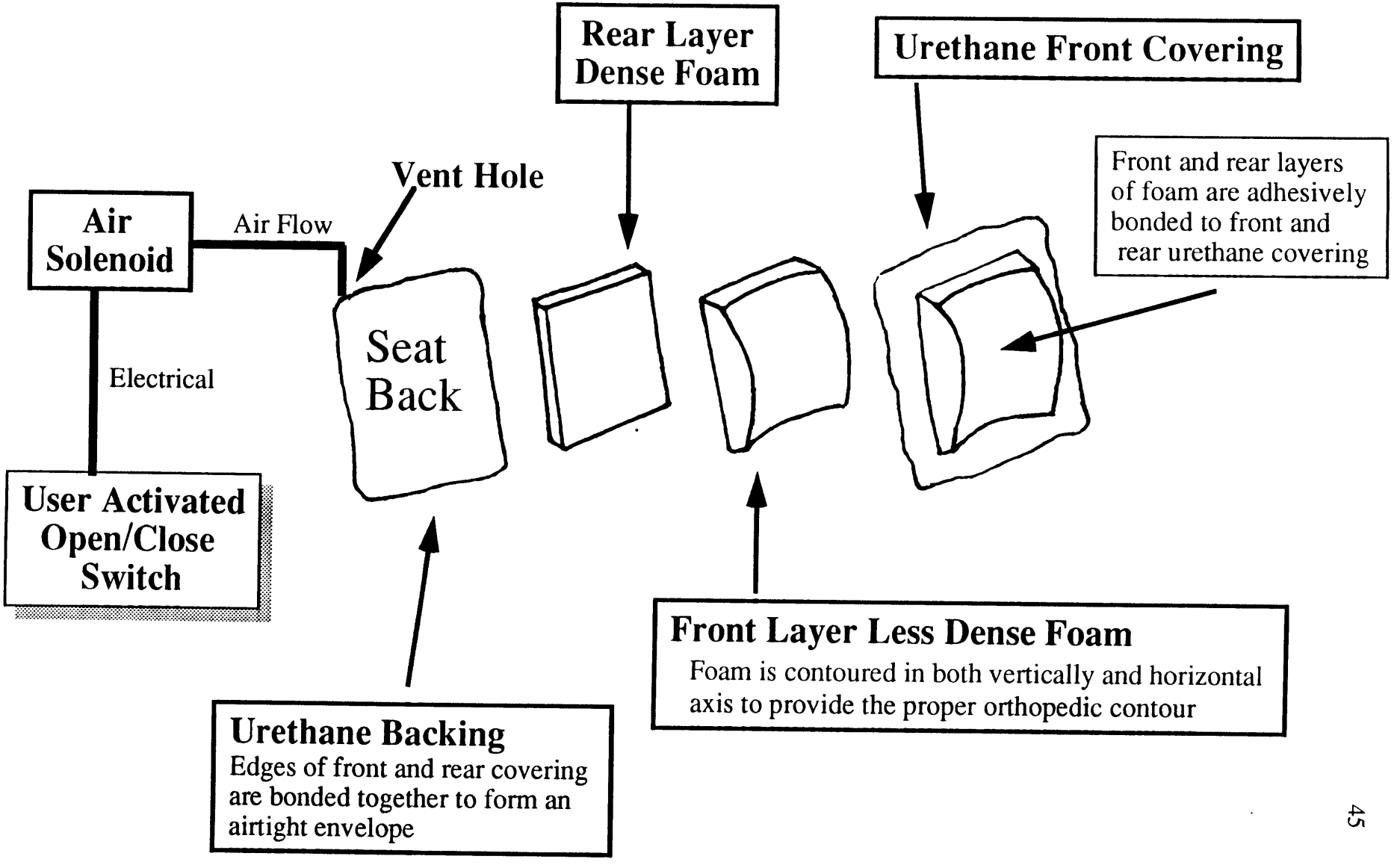


Figure 9

CushAire Family of Products

Firmness

	Soft	Medium	Hard
High Contour	Model HS	Model HM	Model HH
Middle Contour	Model MS	Model MM	Model MH
Low Contour	Model LS	Model LM	Model LH

Figure 10

	Parts					Manufacturing Process					
Customer Options	Rear Layer of Foam	Front Layer of Foam	Urethane Front & Rear Covering	Vent Valve	Air Solenoid & Single Button Control	Cut Contour	Assembly & Bond foams together	Stamp Covering	Bond foam to Coverings	Vac-Form Covering over foam	Install all components in Seat
Model HS	H	H	L	L	L	H	H	L	L	L	L
Model HM	H	H	L	L	L	H	H	L	L	L	L
Model HH	H	H	L	L	L	H	H	L	L	L	L
Model MS	H	H	L	L	L	H	H	L	L	L	L
Model MM	H	H	L	L	L	H	H	L	L	L	L
Model MH	H	H	L	L	L	H	H	L	L	L	L
Model LS	H	H	L	L	L	H	H	L	L	L	L
Model LM	H	H	L	L	L	H	H	L	L	L	L
Model LH	H	H	L	L	L	H	H	L	L	L	L

Degree of Effect on Product Design and Process Steps: H - High, M - Medium, L - Low

Figure 11

CushAire DFM/DFA

- Number of parts: 8
- Utilizing a common manufacturing Process
- Simplified Assembly Operations
- Modular Design of Components
- Simple One-Button Control
- Quiet Operating Mode

APPENDIX 1: TELEPHONE CONVERSATION WITH DR. ROBERT HUBBARD

The following is a compilation of notes taken of a conversation with Dr. Hubbard, Department of Biomechanics, Michigan State University, on February 19, 1992.

- There is no positive way of measuring comfort in a seat. Instead there are ways of measuring discomfort, and associating low levels of discomfort with high levels of comfort.

- Typically, discomfort can be measured indirectly with pressure, since some parts of the body respond differently to pressure. One example is the back of the calves. Applying pressure to the back of a person's calf will result in reduced blood circulation to the lower leg, since the calf region is rich in blood vessels supplying this part of the body.

- Another effect of pressure has to do with local blood flow loss due to the compression of the body tissues affected. The result is the same as one's fingertips turning white when pressure is applied. Over a period of time the body reacts to this pressure by signaling that a change in movement is necessary to improve the circulation.

- One effect of having a poorly designed seat or other ergonomic support is that the body will "fight" the device since basic rules of body geometry are being violated. The ideal situation would be a seat which allows as much of the body's musculature to relax as possible, and takes advantage of the body's own ability to support itself.

- There are ways to measure localized muscle tension (passive tension) with sophisticated medical equipment (electric myography).

- Two different types of comfort exist when evaluating a seat design. One is short term or "showroom" comfort, which is the first impression one receives when sitting in a seat. The other criteria is long term comfort, which can only be evaluated as a result of extended sitting in the seat.

- Dr Hubbard recommended a seat which would adapt to one's changing body position and posture. Some people sit more upright than others, and everyone changes position when sitting, so a the ideal seat, in his opinion, would be one that is adaptive to not only one's size, but also to their good or bad posture, or combinations of these.

- The term "lumbar" support is a misnomer, and the correct term is "lordotic" (sp.?) support. The origins of this type of seat support comes from the Swedish, who adapted an existing car seat (he doesn't name the car manufacturer but it must be Saab.) to better fit the lordotic curve of the lower back.

- Understanding how the human torso moves is essential to understanding which designs will be most successful in providing the kind of support needed. If one sits in a chair and rotates the top of the pelvis forward, the bottom of the ribcage also moves forward. The top of the ribcage then moves rearward. A successful lumbar (or lordotic) support will conform to this kind of movement.

- Studying anatomy books to gain an understanding of the ribcage and pelvis and the musculature supporting them would be helpful to understanding the anatomical consequences of different seat designs.

- When it comes to generating different concepts, simplicity in mechanical design should be a rule, which is specified in the class outline, but also was echoed by Dr. Hubbard.

- The typical GM seat design incorporating bladders to support various parts of the body is anatomically incorrect. This incompatibility is due to the fact that these bladders assume a convex shape when full, which doesn't conform very well to the body's naturally convex shape. The effect is like placing two beach balls together.

- In order to understand the nature of the problem, prototypes should be build as soon as possible, utilizing foam, paper mache or whatever. The concern about a scientific way of determining comfort is valid, but time constraints, in his opinion, prevent that avenue from being exploited as fully as it should. Dr. Hubbard owns a seat consultancy on the side which works with Johnson Controls (a leading supplier of seats to Detroit's automakers) and other firms concerned with seating comfort.

- Dr. Hubbard would be interested in answering further questions that may arise, and also would be interested in visiting when he travels to Vermont in March on a consulting engagement.

Other Contacts:

I also attempted to contact two leading automotive publications, *Car and Driver,* and *Automobile.* Car and Driver Editors were unavailable at the time of my call (meeting) and someone will be calling from Automobile next week (Most Staff Editors are out this week).

From my experience reading automotive publications over the years, these publications typically rely on "seat of the pants" measures to evaluate seat comfort. Typically they are evaluating automobiles as a whole and there is plenty of data relating to objective measures of performance than can be easily determined (e.g. horsepower, braking distances, displacement, etc.).

These people also have the benefit of evaluating several different models and makes of vehicles over a very short period of time, so they could be a valuable source, depending on willingness, of information regarding to vehicles with the best seat comfort and/or adjustability.

APPENDIX 2: CUSTOMER COMFORT CLINIC SURVEY RESPONSE FORM

Please complete the following questionnaire prior to beginning the seat testing portion of the clinic.

Name: _____

Sex: M F

Age: _____

Height: _____

Weight: _____

How often do you drive? _____

What car (make/year) _____
do you drive most often?

What is your car preference? Sport
Family
Luxury
Truck/Van

Have bought a car or had a part in the decision to buy a car? _____
If yes, did you consider the seats in your buying decision? _____
Scale of Importance low_____|_____high

Have you ever driven a car with a controllable lumbar support system? _____
If so, what did you think? _____
_____
_____
_____

Back trouble? Currently? _____
In the past? _____

General comments about automobile seats: _____
_____
_____
_____
_____

SEAT COMFORT CLINIC
LUMBAR SUPPORT PROJECT

SEAT # _____

Customer Name _____

Lower Back (Lumbar) Comfort and Support (at most "comfortable" position)

Comfort Criteria

Back Firmness

☐ Too Firm ☐ Too Soft ☐ Just Right

	Very Uncomfortable	Uncomfortable	Somewhat Uncomfortable	Neutral	Somewhat Comfortable	Comfortable	Very Comfortable
Back Firmness	☐	☐	☐	☐	☐	☐	☐
Lower Back (Lumbar)	☐	☐	☐	☐	☐	☐	☐
Back Width at Lumbar	☐	☐	☐	☐	☐	☐	☐
Lateral (Side) Support	☐	☐	☐	☐	☐	☐	☐
Vertical Location of Support	☐	☐	☐	☐	☐	☐	☐

Support Criteria

	Very Inadequate Support	Inadequate Support	Slighly Inadequate Support	Neutral	Just Adequate Support	Acceptable Support	Very Good Support
Lower Back (Lumbar)	☐	☐	☐	☐	☐	☐	☐
Lateral (Side) Support	☐	☐	☐	☐	☐	☐	☐
Vertical Location of Support	☐	☐	☐	☐	☐	☐	☐

Adaptability Criteria

Changes from controls

☐ Could feel the Change ☐ Felt No change ☐ Uncomfortable changes

Ease of use for controls

☐ Easy to control ☐ Neutral ☐ Difficult to Control

Comments (on back of sheet)

APPENDIX 3: CUSTOMER COMFORT CLINIC SUMMARY OF RESULTS

Seat 1

Cutlass Sierra (hand pump bladder lumbar system)

																Average	Std Dev.
Back Firmness	2	2	3	2	2	2	2	2	2	1	2	2	2	2	2	2.00	0.38
Comfort																	
Back Firmness	4	6	5	5	6	5	6	4	4	3	5	7	4	6	6	5.07	1.10
Lower Back	5	6	5	6	7	4	5	6	6	6	6	7	5	6	5	5.67	0.82
Back Width	2	5	6	6	3	6	6	4	2	7	3	6	5	7	3	4.73	1.75
Lateral Support	2	6	5	4	3	4	6	2	5	5	3	5	4	7	3	4.27	1.49
Vertical Location	6	6	5	6	6	3	6	3	5	2	6	6	2	5	4	4.73	1.53
Support																	
Lower Back	6	6	5	4	5	4	4	5	5	7	7	7	4	6	5	5.33	1.11
Lateral Support	6	6	5	4	3	4	7	1	3	2	4	5	5	7	4	4.40	1.72
Vertical Location	6	6	5	4	5	4	6	4		2	7	6	1	2	5	4.50	1.79
Adaptability																	
Changes from Controls	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3	2.93	0.26
Ease of Use	3		1	1			3			3	3	2	3	3		2.44	0.88

Seat 2	Pontiac Grand Am (bar lumbar system)																Average	Std Dev.
Back Firmness	2	2	3	3	3	2	2	2	3	2	2	2	2	2	2	3	2.31	0.48
Comfort																		
Back Firmness	4	4	4	3	4	6	6	6	4	6	6	7	5	7	7	4	5.19	1.33
Lower Back	5	4	2	3	3	6	6	6	5	3	5	7	5	7	6	4	4.81	1.52
Back Width	4	3	2	4	5	4	6	5	4	6	6	6	5	6	4	4	4.63	1.20
Lateral Support	3	6	3	3	6	5	6	4	2	6	6	6	5	7	5	4	4.81	1.47
Vertical Location	5	3	6	3		7	6	6	5	2	6	5	3	7	4	4	4.80	1.57
Support																		
Lower Back	4	2	2	3	5	4	6	5	4	3	6	6	6	6	4	5	4.44	1.41
Lateral Support	5	6	3	4	5	4	6	5	2	1	5	6	5	6	4	3	4.38	1.50
Vertical Location	5	4	4	2	4	4	6	5	4	2	6	6	2	6	4	4	4.25	1.39
Adaptability																		
Changes from Controls	3	3	2	3	3	3	3	3	2	3	3	3	3	3	3		2.87	0.35
Ease of Use	1	1	1	2	1	1	1	1	1	1	3	1	1	2	1		1.27	0.59

Seat 3	Cadillac Allante' (Schukra lumbar system)																Average	Std Dev.
Back Firmness	2	2	2	2	2	1	2	2	2	2	1	1	2	2	1	2	1.75	0.45
Comfort																		
Back Firmness	6	6	7	6	7	3	6	6	6	6	3	6	5	6		7	5.73	1.22
Lower Back	6	7	7	7	5	3	7	7	6	6	3	6	6	6	6	7	5.94	1.29
Back Width	6	3	6	5	6	5	7		6	7	6	6	3	6	4	5	5.40	1.24
Lateral Support	6	5	5	4	3	3	7	2	2	6	4	4	4	5	4	3	4.19	1.42
Vertical Location	7	7	6	6	6	3	7	6	6	3	6	2	3	5	4	7	5.25	1.69
Support																		
Lower Back	7	7	7	7	6	4	6	7	6	3	6	7	6	6	6	7	6.13	1.15
Lateral Support	6	3	5	3	3	4	7	4	4	2	4	5	4	5	4	4	4.19	1.22
Vertical Location	7	4	6	6	5	3	6	5	4		6		2	6	5	7	5.14	1.46
Adaptability																		
Changes from Controls	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3.00	0.00
Ease of Use	3	3	1	2	3	1	3	3	3	3	3	3	3	3	3	3	2.69	0.70

Seat4	Corvette (Bladder system)															Average	Std Dev.
Back Firmness	2	1		2	1	2	1	2	2	1	2	2	2	1	1	1.57	0.51
Comfort																	
Back Firmness	5	4	6	6	3	5	5	6	3	4	5	6	5	6	4	4.87	1.06
Lower Back	4	5	5	5	3	6	6	7	5	4	6	6	5	6	3	5.07	1.16
Back Width	3	5	6	6	6	6	6	6	2	6	4	7	5	6	7	5.40	1.40
Lateral Support	6	3	6	5	5	3	6	2	2	2	1	2	1	4	1	3.27	1.91
Vertical Location	6	3	7	3	6	4	7	6	6	2	5	5	3	6		4.93	1.64
Support																	
Lower Back	6	6	6	6	4	4	6	5		2	5	6	6	6	2	5.00	1.47
Lateral Support	6	3	7	6	5	4	6	4	5	4	6	4	4	7	1	4.80	1.61
Vertical Location	6	3	6	3	5	4	7	4	2	2	6	1	2	6	4	4.07	1.87
Adaptability																	
Changes from Controls	3	3	3	2	3	3	3	3	3	3	3	3	3	3	1	2.80	0.56
Ease of Use	2	1	2	1	3	1	2	3	1	1	2	2	2	2	1	1.73	0.70

APPENDIX 4: SUMMARY OF CUSTOMER RESPONSES FROM SEAT COMFORT CLINIC

Legend :

Seat # 1 - Cutlass Sierra (Hand Pump bladder system)

Seat # 2 - Pontiac Grand Am (Bar Lumbar System)

Seat # 3 - Cadillac Allante (Schukra System)

Seat # 4 - Corvette (Bladder System)

Customer Responses

Customer 1:	F 29 5'5"
Importance of Seats:	4
Back trouble:	Yes / yes
Controllable Lumbar:	Yes. Nice once you get the hang of it.
General Comments:	I like the curve of my Mazda. The curve is different in Mazdas. Hate non-cloth seat covers. I like some ability to adjust the lumbar.
Seat #1:	Lateral support too close.
Seat #2:	Too narrow a seat.
Seat #3:	
Seat #4:	
Customer 2:	M 31 5'11"
Importance of Seats:	3
Back trouble:	Yes / yes
Controllable Lumbar:	Yes. Good if it is not too difficult to use.
General Comments:	
Seat #1:	Back width - just about right Adjustments - responsive General - good seat, simple and responsive
Seat #2:	Side Support - curved wings work well General - annoying control
Seat #3:	Back width - could be a little wider lumbar area Adjustments - very adaptive General - noise is horrible
Seat #4:	Lower back - good contour Lateral support - in the way Vertical location of support - a little high Control - difficult to control for comfort General - the controls allows for customized fit, but are also difficult to adjust.
Customer 3:	M 27 5'10"
Importance of Seats:	3
Back trouble:	Yes / yes
Controllable Lumbar:	Yes. It made a long drive much easier.
General Comments:	
Seat #1:	
Seat #2:	Lumbar - not enough support Back width - too small Lateral support - too wide Adjustment - couldn't feel much change
Seat #3:	General - too noisy
Seat #4:	

Customer 4: M 28 6'3"

Importance of Seats: 2
Back trouble: Yes / yes

Controllable Lumbar: no.
General Comments:
Seat #1: General - I had to keep pumping the bulb to notice only a minimal change.

Seat #2: General - Seat is too soft and mushy. No active lumbar support.
typical of GM seat.

Seat #3: General - Side support feels uncomfortable.

Seat #4: General - Seat is comfortable (is firm), but controls don't provide much feedback. It doesn't feel like anything is happening. Air system sounds like it is farting.

Customer 5: M 26 6'2"

Importance of Seats: 3
Back trouble: No / no
Controllable Lumbar: Yes. Nice, comfortable on long trips.

General Comments:
Seat #1: Back width - needs to be a little wider
Lateral support - needs to be more curved, not such a big gap.

Seat #2: Back firmness - too soft, least comfortable
Lumbar - a bar, not even distribution of support
Side support - better than others
Changes from control - not too much
General - Not as comfortable driving

Seat #3: Lateral - doesn't do much
Vertical location - pretty big range
Ease of control - could feel each control
General - don't like noise

Seat #4: Changes - couldn't feel as much as in seat #1. Don't like noise.
General - Good to customize. Too hard in lumbar, not enough cushion

Customer 6:	F 26 5'6"
Importance of Seats:	3
Back trouble:	No / no
Controllable Lumbar:	No.
General Comments:	Seats need to be comfortable for both short and long trips. Should be easily adjustable. Should facilitate entry and exit from vehicle (e.g. the sides should not get in the way).
Seat #1:	Lateral support - a little annoying. Vertical location - needs to be a little higher. General - alright, not great.
Seat #2:	Back firmness - better than 1, softer Side support - in the way Vertical location - hits the right place General - To control it once and leave it alone would be ok, but not often.
Seat #3:	Firmness - a little too firm. Lateral - still in the way. Vertical location - a little high on the back. Ease of control - still difficult to control. General - bad noise, has got to go.
Seat #4:	Lower back - ok when it is all the way deflated. Lateral - still too much. Changes - not as obvious. Ease of control - too complicated. General - Wouldn't deal with the controls, Don't like leather. Hard to get out of the seat.
Customer 7:	M 24 5'7"
Importance of Seats:	4
Back trouble:	No / no
Controllable Lumbar:	No.
General Comments:	Must be comfortable.
Seat #1:	Lumbar - seat 2 is better, softer should be more stiff. Vertical location - Should be higher, V-shape.
Seat #2:	Lumbar - upper portion is not comfortable, gap in between. Side support - should be higher along sides. General - Knob in bad location.
Seat #3:	General - The best seat in the test.
Seat #4:	General - Very poor upper back and neck design, support for head.

Customer 8: F 20 4'11"
Importance of Seats: 4
Back trouble: No / no
Controllable Lumbar: No.
General Comments: Must be comfortable.

Seat #1: Vertical location - Should be higher.
Lumbar support - not the right place.
Side support - a little lame.

Seat #2: General - Knob in bad location. Headrest not good. Fabric bad, can't slide easily.

Seat #3: Lumbar - a lot more support.
Side support - too much.
Controls - more responsive, in a good location easy to use.
General - good, can slide in it.

Seat #4: Lumbar - span is larger for support.
Change from controls - felt it in 3 places, not all the same.
General - A lot more freedom with controls. Didn't like side support.

Customer 9: F 40ish 5'8"
Importance of Seats: 4
Back trouble: No / yes
Controllable Lumbar: No.
General Comments: Uncomfortable in most bucket seats. I like bench seats. Don't like too high a headrest.

Seat #1: Firmness - Firmer than #2.
Back width - too small.
Lumbar support - not the right support.
Side support - needs to be wider.
General - many bad things about the seat. Hip span of seat is too small. Cushion is too small.

Seat #2: Firmness - likes it firmer.
General - Would not buy a car with this seat in it. Seat angle is wrong. It would be very difficult for an older person to operate. Need a certain torque. Controls should be on the side.

Seat #3: General - most responsive controls, but I wouldn't bother with them after awhile.

Seat #4: Lumbar - hits me wrong.
Change from controls - hard to control.
General - I would keep it set all the time. Can't control while driving. Hard for an older person. Neck hits at a bad angle, hip support not wide enough.

Customer 10: M 27 5'6"
Importance of Seats: 4
Back trouble: Yes / yes
Controllable Lumbar: No.
General Comments: Lumbar support is the most important for me, followed by side support (for high speed driving). Lumbar support adjustable for height would be good.

Seat #1:
Side support - not enough.
Vertical location - too high.

Seat #2:
Side support - not enough.
Controls - couldn't feel much in the lumbar.

Seat #3:
Firmness - too firm for long trip?
Side support - not enough.
Vertical location - too high. Not enough adjustment to lower back.
Lumbar - didn't go out far enough.
General - sports car driver likes leg and back side support.

Seat #4:
Firmness - light person, not enough foam, needs to be softer.
Lumbar - position wrong
Vertical location - too high. Not enough adjustment to lower back.
Side support - not enough.
General - Needs more shoulder, more side adjustment and more side comfort.
Don't know when air is full.

Customer 11: M 24 6'0"
Importance of Seats: 2
Back trouble: No / no
Controllable Lumbar: No.
General Comments:

Seat #1:
General - the seat is not wide enough.

Seat #2:

Seat #3:
General - The seat is too firm, and too curved. The lumbar device is a bit too high.

Seat #4:
General - Seat is too narrow.

Customer 12:	F 27 5'5"
Importance of Seats:	4
Back trouble:	/ yes
Controllable Lumbar:	No.
General Comments:	Prefer bucket seats. Placement awkward for short people, either too low or too far back.
Seat #1:	Firmness - seat is too firm. General - would have preferred a button rather than a pump. Neck support is a problem. Would like a more adjustable headrest.
Seat #2:	General - Difficult to adjust lumbar support control knob. Adequate neck support but can be improved. Lumbar support placement a little high. Would prefer height adjustability.
Seat #3:	Firmness - on the firm side. Side support - not enough. Vertical location - just didn't fit. General - Good lumbar support but placement is too high, i.e. does not hit my lumbar area. If you could adjust the height of the support, it would be great. In fact, adjustability is necessary for comfort because location of needed support changes with posture and time.
Seat #4:	Controls - side support controls should be within reach since this would change as trip progresses. Good placement of lumbar support controls. General - Very uncomfortable neck support. Neck is forced forward and not supported. No matter how comfortable the lumbar area is, if the whole back is not supported, you'll have major problems - just ask a chiropractor! Lumbar support could be better if an additional "bag" were placed lower for additional support.
Customer 13:	M 28 5'11"
Importance of Seats:	2
Back trouble:	No/ no
Controllable Lumbar:	No.
General Comments:	Lumbar support is the most important for me, followed by side support (for high speed driving). Lumbar support adjustable for height would be good.
Seat #1:	General - lumbar support is too high.
Seat #2:	
Seat #3:	
Seat #4:	
Customer 14:	M 21 5'10"
Importance of Seats:	
Back trouble:	Yes
Controllable Lumbar:	No.
General Comments:	
Seat #1:	General - Side support position is nice.
Seat #2:	Controls - lumbar support knob is hard to move while seated.
Seat #3:	General - Too straight; lumbar support too hard, flat, and too high.
Seat #4:	General - Buttons are confusing; one has to get rather uncomfortable at times. Lateral supports are too large (forward).

Customer 15: M 43 5'7"
Importance of Seats: 1
Back trouble: no
Controllable Lumbar: No.
General Comments: I in general have not paid much attention to car seats.

Seat #1: Side support - A little too much .
General - just able to tell the support is there. Provides adequate support. Supports changes as you move.

Seat #2: Firmness - Comfortable, firm but not real hard.
Side support - contours to back.
General - Like covering. Very comfortable seat. It gives enough that it fits well to the body. Pelvic is supported well. Still provides firm support.

Seat #3: Side support - stick out too much.
Vertical location - good to have adjustment.
General - Prefer seat #2 since it hugs you better. Problem with leather versus cloth. Overall I like this seat.

Seat #4: Lumbar - not uniform support.
Controls - not reproducible, unacceptable.
General - Lumbar support feels like sausages/salami pressed into my back. Does not "give" as much as the others.

Customer 16: older

Seat #2: Firmness - can't be too firm.
General - would like to have a seat belt restraint system which prevented you from slumping in chair over time. Helps to maintain seat posture.

Customer 17: F
Back trouble: Yes / yes
Controllable Lumbar: No.

Seat #3: Width - a little wide.
Side support - like less support.
Controls - good. In my Fifth Avenue I have to open the door to adjust the seat.

APPENDIX 5: SUMMARY OF COMMENTS FROM NATIONAL NEWS GROUP BULLETIN BOARD

Rec.autos

These following excerpts are taken verbatim from the e-mail I received in response to my posting in the rec.autos newsgroup on athena. The lines separate the opinions from each individual.

"Both of my cars ('69 MGB and '75 Olds Cutlass Supreme) have straight seat backs. The Olds is a bench and the 'B is a bucket, of sorts. Both of them are fairly comfortable although they provide neutral lumbar support. As such I don't use any [additional] devices.

"The seats which I really object to are the ones that attempt to provide lumbar support and miss my lumbar. Airline seats and some auto seats are a perfect example of this. The lumbar support hits me in the upper pelvis and then there is an indentation right at my lumbar region. Finally, there is usually some sort of head or neck support which hits me just above the shoulder blades. This works to ensure that my back is bent into the worst possible form.

"For me the perfect seat would have some sort of device in it to allow the position of the lumbar support to be moved up and down (as well as in and out) and which would allow similar adjustment to any neck or head support."

"I recently purchased a 1991 Chevy S10 Ext. Cab with the reclining bucket seats. They were the most comfortable seats of any of the small trucks which I drove, but I would still rate them as awful. The reason? I am 6'3" tall and the sides of the bucket where they curve into the neck support hit me just below the shoulder blades and are really annoying after more than about 1hr. Also, the head rest is not adjustable, however, even on the seats which had an adjustable head rest, it was not high enough for me to adequately rest my head while driving. Furthermore, I would like to see a head rest which can be rotated forward or backward somewhat from its normal upright position. This would provide extra comfort. (I think some safety regulations may prohibit how much movement, if any, is possible.)"

"After about 1hr. of driving I start to get cramps in the latisimus muscles, from having the bucket seat wings hit me below the shoulder blades, hence leaning me forward.

"If I could afford it, I would have custom seats installed. All of the automakers offer only 1 standard bucket seat, which is supposed to fit everybody. I wan one that can be elongated, i.e. the seat back can be raised and lowered."

"My current car is a 1986 VW Jetta GLI. I LOVE the seats in this car. They are very firm, have excellent thigh and side bolsters, and give a good balance of lumbar support."

"They are extremely comfortable for most trips."

"The seats have no adjustable lumbar supports. I would add an inflatable lumbar support to the seat, and also some type of device adjustment to allow me to raise/lower the primary area of lumbar support. Everyone likes lumbar support at slightly different areas of their back, it seems."

"I own a Honda and a VW. The Honda seats are generic, but very firm and comfortable, though not nearly as comfortable as the VW's. Since I own foreign cars, I always make it a point to rent American cars whenever I travel on business, just to see how they are doing. I recently rented a 1991 Sunbird. It had, without a doubt, the absolute WORST seats I have ever sat in. I would rather have had a folding metal chair bolted to the floor of the car. The seats were too low, had NO lumbar support, offered No lateral support, and felt as if they were stuffed with cotton balls."

"[My seat] makes my lower back hurt after a couple hours."

"[I would] add a lower back support."

"I use a pillow when taking long trips.

I own a 1988 Oldsmobile Cutlass Cruiser (station wagon)."

"I'm not too particular about seats. I use no pads, etc. However, I also am unlikely to ever buy a new car.

"My wife, on the other hand, bought a new car a couple of years ago -specifically- for the seats. She has had bad back problems and cannot sit for long periods. She takes a lumbar support cushion everywhere. However she found that the Lincoln MkVII had seats which she can tolerate better than any others; they have fully adjustable lumbar and thigh supports (electric air bladders; she would be unable to work the manual crank type), electric adjustment of back angle (recline) and seat angle/position. Without this kind of seating she would be unable to drive any distance. She can't ride in my car even with a cushion because the seat recline is not adjustable.

"So there's two opposite data points: note that people who really need good seats will pay highly for them and people who don't, don't care.

"With the relative simplicity of swapping seats, I think they ought to be a dealer-installed option; every manufacturer should make top-of-the-line sport/support seating available as a profit item. Look at how thieves were going after Toyota Supras a few years ago, just to get the spiffy seats to sell to Celica owners. Seating is probably the most personal aspect of a car."

"I am a daily commuter with a slightly bad back. I don't use any extra stuff in my seat to make it better.

"I have an 83 RX-7, whose seats I like more or less; I especially like the sides of the seat, which stick out a lot farther than the middle to hold me in place (both on the vertical part and especially on the horizontal part).

"I had an 89 MX-6 whose seats I liked a little better because of the part that stuck out which got under my lower back and held it up, but it did not in my opinion go far enough, especially for long trips, and tilting the seat back only made it worse.

"I would like to see (sit on) a lower back piece which comes out farther on the sides than it does in the middle in order to conform to the sides of my body, which are curving away from the seat.

"But the most important thing for me is that the center of the steering wheel be in line with the center of the seat, that the gas pedal be off to the right enough so that the brake is off center to the right also (yet maintaining enough room between the gas and the center column so that I don't hit it with the side of my foot every time I reach for the gas), and that the left foot rest (automatic) / clutch (manual) is not so far over to the left that it is difficult to reach. It would be nice if the left foot rest were adjustable. All this is so that I don't have to _twist_ while I'm driving; that feels awful and hurts my back (especially on long trips). My mom's '80 Le Mans has the steering wheel and brake left of center of the seat; very annoying. My RX-7 has a left foot rest so far on the side that it is unusable and I am considering sticking a piece of wood to it to make it reach where my left foot wants to be. My MX-6's foot rest was in just the right place.

"No seat in the world will help if you have to sit in it twisted because of the layout of the controls."

"Current Automobile: 1991 Nissan Sentra E 2-Door

"Average Hours Driving per Week: 14 Hours

"I have the low end bucket seats that are the standard with the Sentra. For the most part, they are comfortable, but they need additional support in many areas which I will highlight.

"Seat bottom. Cushioning needs to be firmer. I prefer a leather seating surface, as it allows for better movement and shifting (unfortunately mine are cloth). The front of the seat should be higher than the back by a large degree. I like to have my thighs just higher than my waist. This cant should be adjustable. The lower back (lumbar area) needs to be padded more firmly and should be a little more protruding, so as to fill the small of my back. I don't have back problems, but on long trips, this is one area that screams for comfort after about 3-4 hours. The side bolsters should be much bigger, wrapping around my ribs almost, and should be firm enough to hold me in position around tight corners. My BIGGEST complaint with seats is the headrest. The worst implementation is that by Volvo. Plastic grids are NOT comfortable. The small rubber headrest with my car is not fantastic either. I prefer one of two types of headrests. A) A simple rounded rectangle that is both height adjustable, as well as able to tilt fore and aft. This is a nice feature, so as to fit it just in the curve between the top of the back and the base of the skull. B) The type which look like an 'O' a large square with the middle missing.

"The best seats I have ever sat in were those in the 1988 and 1989 Mitsubishi Starion/Chrysler Conquest."

"I own an 1984 VW Quantum. In general, I like my seats, but they are not perfect. My background: I do have some lower back pain (my seat at work is not so great, but my employer is too cheap to spring for a better one). I'm 28, and I sit in front of a computer all day, so my back hates me.

"As for my car seats, they're fabric (velour?) covered bucket seats with good side supports (along the hips and ribs) to avoid moving side to side. But, the ONE thing I wish they had was an adjustable lumbar support. The lower back part of the seat is nearly flat, and does not provide enough support. If I'm driving more than about 1-1.5 hours my back starts hurting. I can increase the length of time I can drive comfortably by changing the seat back angle from about 75-80 degrees (normal position) to 45-55 degrees. This gives me about 2 extra hours of reasonable comfort while driving. Note that this only happens when I'm DRIVING. If I'm a passenger (same car, same seat), my back never hurts. I'm not sure if the difference is because I can move around more, or I don't have to hold my hands on the steering wheel, but the difference is large. I don't think the pedals are the problem because I have cruise control, and my back hurts even if I don't have to use the pedals for long periods of time.

"I've always wished this car had lumbar support adjustment, like my old Volvo had. I've had limited success using rolled up towels and such while driving; that tends to change the ache in the muscles to a tingling pain in the spine; also not pleasant. I've taken more to letting my wife drive the long trips and just enjoying the scenery."

"P.S. The Volvo I spoke of (1978 245DL) had the most comfortable seats I ever drove long distances in. Both the vinyl and cloth covered models were outstanding (we had vinyl and replaced them with cloth at one point). The only problem with them was that the lateral support was not so great - I guess they didn't expect the drivers of those cars to whip around corners very fast."

"I have a Ford Probe GT. The driver's seat is power adjustable with 3 position lumbar support, and side bolster support. It's a little uncomfortable in drives longer than an hour."

"[The seat's] too soft in support. I think it should be firmer. The Hondas I've ridden in have much better support in my opinion."

"[I would make my seats] firmer, make the lumbar support are a little larger."

"Sometimes when I'm driving long distances, I get so irritated with the softness of the seat that I'm almost tempted to go out and buy aftermarket seats and put them in.

"I've ridden in a Pontiac Bonneville SSE w/ 3 adjustable areas of back support. I thought this was really good for adjusting positions."

"I have a 1981 BMW 733i, and one of the reasons that we purchased it was specifically for the seats. I suffer from lower back pains, and our Hyundai Pony seemed to aggravate the problem.

"I love [the seat]. Despite the car's age, I think that they are one of the best designed seats that I have seen. Just last weekend I went to the Canadian Auto Show and looked at quite a few cars. Very few did I find that had seating comparable to ours. Some of the ones that I liked were Volvo, and Volkswagen."

"The seats provided excellent lateral support, as well as lumbar support. My spine seems to need a lot of lumbar support to feel comfortable. I also find that many cars these days have seats which are too low. In the economy class I feel Volkswagen distinguishes itself

for good upright seats. Another feature which makes seats comfortable for driving are adjustable head rests front and back. Again, although many cars offer them for the front now, our 11 year old car has them all around making passengers very comfortable."

"[I would like] adjustable lumbar that could be moved up and down for individuals of varying heights."

"At the office I have an Obus Forme with a lumbar pillow which is terrific, and without which I get back pains after a few days sitting. However, on our car there are no supplementary devices. We regularly drive from Toronto to New Jersey (about 500 miles) and my back never acts up.

"I mostly drive on the highway although we do live in a large metropolitan area (it is much easier to use public transit in the city). Average driving trip, therefore, is about 60 miles (one way) done about 3 times a week..

"Other things of note: My height is 5'11", and most of that is in the legs so this is why I might like higher seats. Sorry, scratch that. My wife is only 5'2", and she like higher seats as well.

"In general, I think that most car seats suffer from inadequate lateral as well as lumber support, and are positioned much too low.

"BTW, one of the small cars that I am really impressed with for its seats is the new Saturn."

"[My seat's] comfortable since it has enough support on the sides to see that I don't get thrown around when I take turns. This is both at the thighs and at the 'flanks'. Also, it's firm and so you body doesn't sag into it.

"It's uncomfortable because I don't have enough support at my lower back. I have a slight hunch that I'm trying to correct. The seat doesn't help too much with that. I don't have any problem with regular commuting, but on the only occasion when I drove for about 6-8 hours in a day, my back hurt a bit. Once I stretched my back it was okay."

"[I would] re-shape the back so that I get that extra support for the lower back."

"I'm a daily commuter. It's 10 miles between home and work, so that's 20 miles a day. My wife and I do take an occasional long trip, though we usually restrict ourselves to a 50 mile round trip. As long as I exercise regularly, I don't have any back problems."

"The (leather) seats on my '90 model Nissan are generally fine, but could benefit from a few improvements."

"They are perfectly comfortable for short duration trips, but on long, cross-country treks they tend to make my tail bone sore, (given that it is a sports car)."

"[I would like] more padding in the base of the seat. The side bolster (? is that the correct term?) adjustments are irrelevant to me, as I am content to leave them in any position."

"The lumbar support in this vehicle is a manual operated type (in or out) and, when in the 'out' position often is not in a comfortable place, (given I often change my position in the seat during a 3-4 hour interval."

"I have two cars:

(1) Nissan Sentra 87: its driver seat is a bucket-shape one with little lumbar support. While it is OK to ride on it for a short trip (under 30 min drive), I feel very uncomfortable (especially my lower back) for a longer trip.

(2) Honda Civic 4dr 89: its driver seat is less sporty-look than my Sentra and has rarely any lumbar support. Its seat height is also unusually lower than average seat height of cars in its same class (subcompact). The result is that you can hardly sit on it with your back straight. The only way to relax your legs while sitting on it is to stretch them forward, but that makes my lower back more uncomfortable."

"After I say my physical therapist regarding my lower back pain, she suggested me to put a small pillow between my lower back and the seat to enhance the lumbar support. Since then, I feel much better.

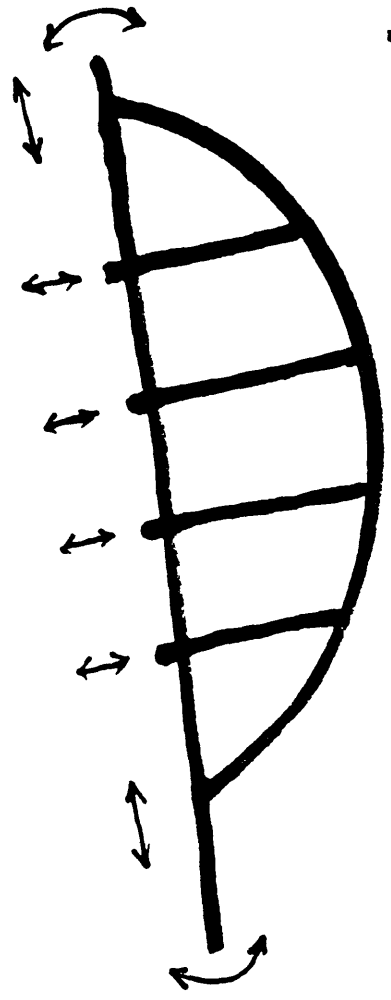
"I think a better car seat is the one with more adjustable features, such as seat height, headrest, lumbar support, and back-support incline degree. Also, each of these adjustable features should have a wide enough range to fit the diverse preferred sitting positions of different people. I know many lux cars have these features, so the problem now is how to add these features to almost every cars with minimum costs (just like air bag and ABS)."

APPENDIX 6: INITIAL DESIGN CONCEPTS

MODIFIED SCHUKRA A

(5 Mar 92)
75

Lumbar support

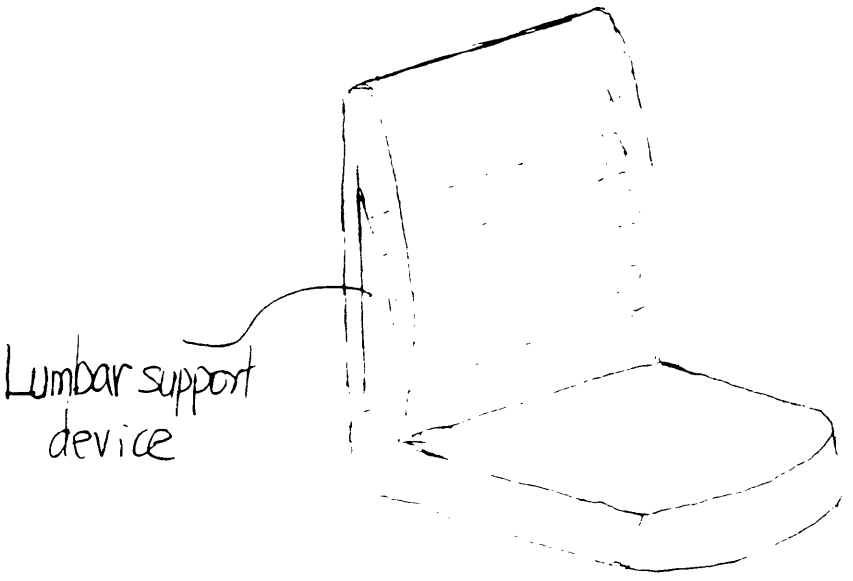


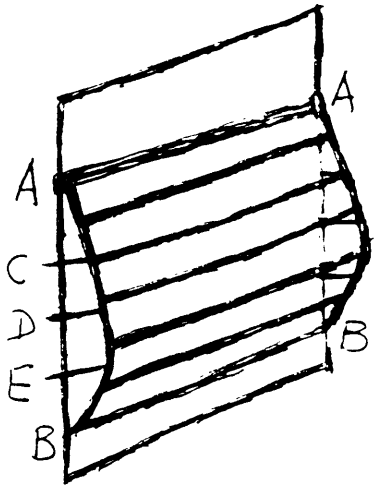
Individually adjustable to achieve the desired curvature

↔ means movable

Advantages:
i) Simple (low cost)
ii) Manufacturable
iii) Meets the primary criteria
iv) Fits the mission statement
v) Safe

Schukra-type Lumber Support System





Mechanism: A,B, movable(up/down)
C,D,E,movable(back/forth)

Control: Mechanical/Electrical

Advantages: Provides the necessary "threefold support" of an ergonomically "optimal" backrest as identified by Schukra:

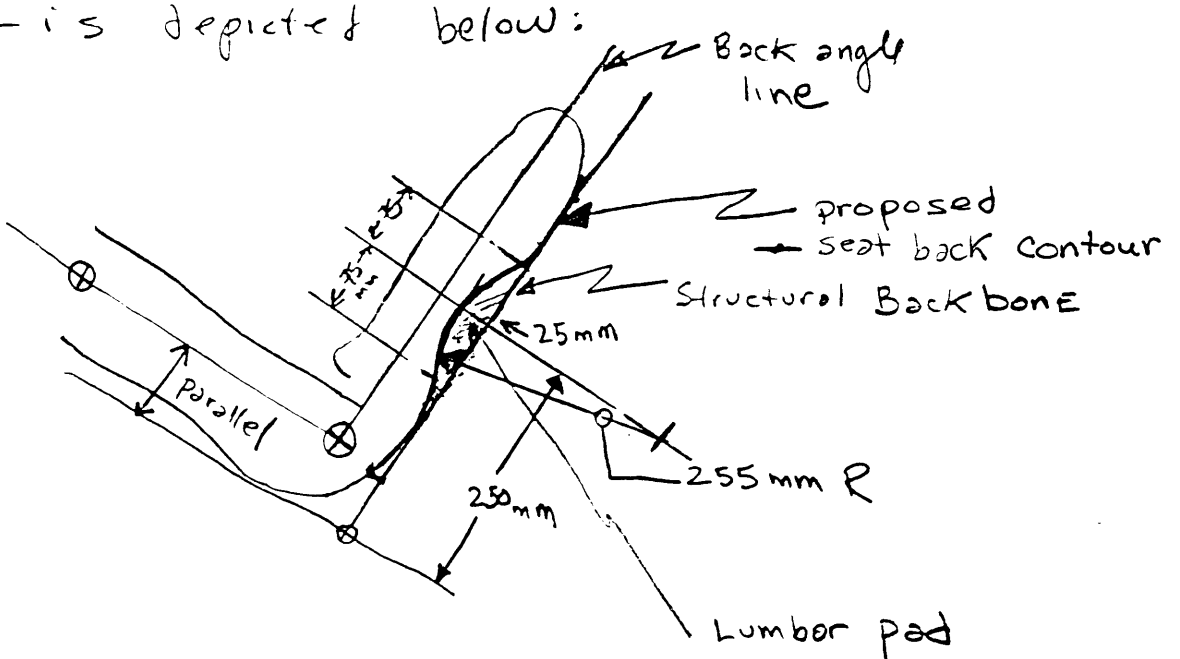
(1). pelvis support;
(2). Single vertebra support;
(3). body support.

Additional feature is that more variation of the curvature of the support device is allowed.

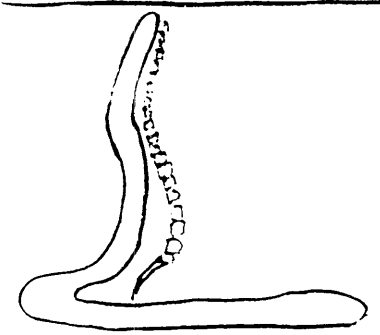
General features: simple, manufacturable, ergonomically "correct".

"Structural Backbone" Lumbar Support Concept

The lumbar support mechanism would be build in a separate pod which could be moved up and down to position at the appropriate location. The pod would be a steel or blow molded section which can be purchase in three sizes (s, m, L). The covered lumbar area is depicted below:



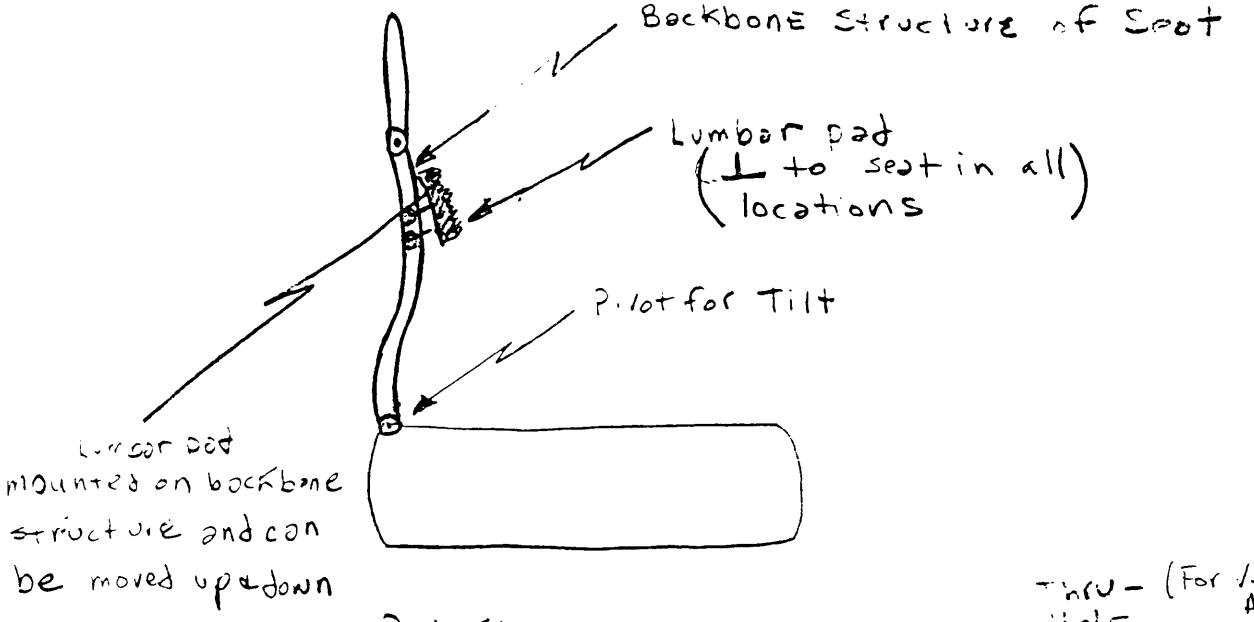
Seat Contour



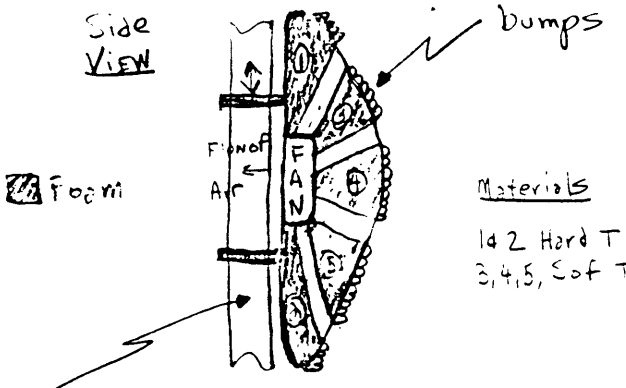
Seat contour is molded to the contour of ideal spinal.

Lumbor adjustment

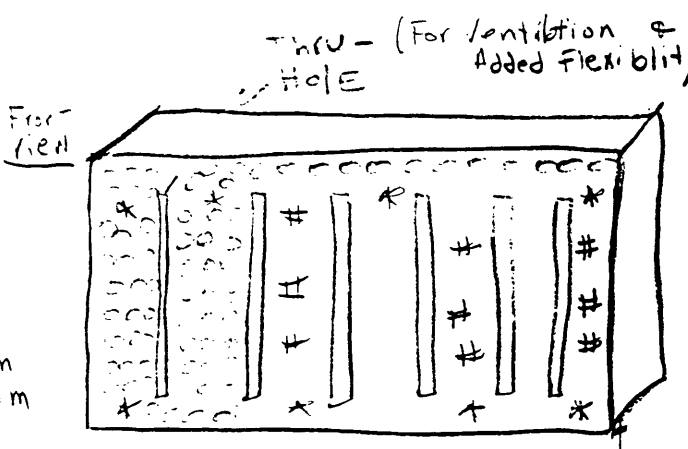
- pillow design - foam enclosed in a sack. The pressure of the sack is controlled by the user by releasing air & readjusting his posture.



Lumbar Pad Shape



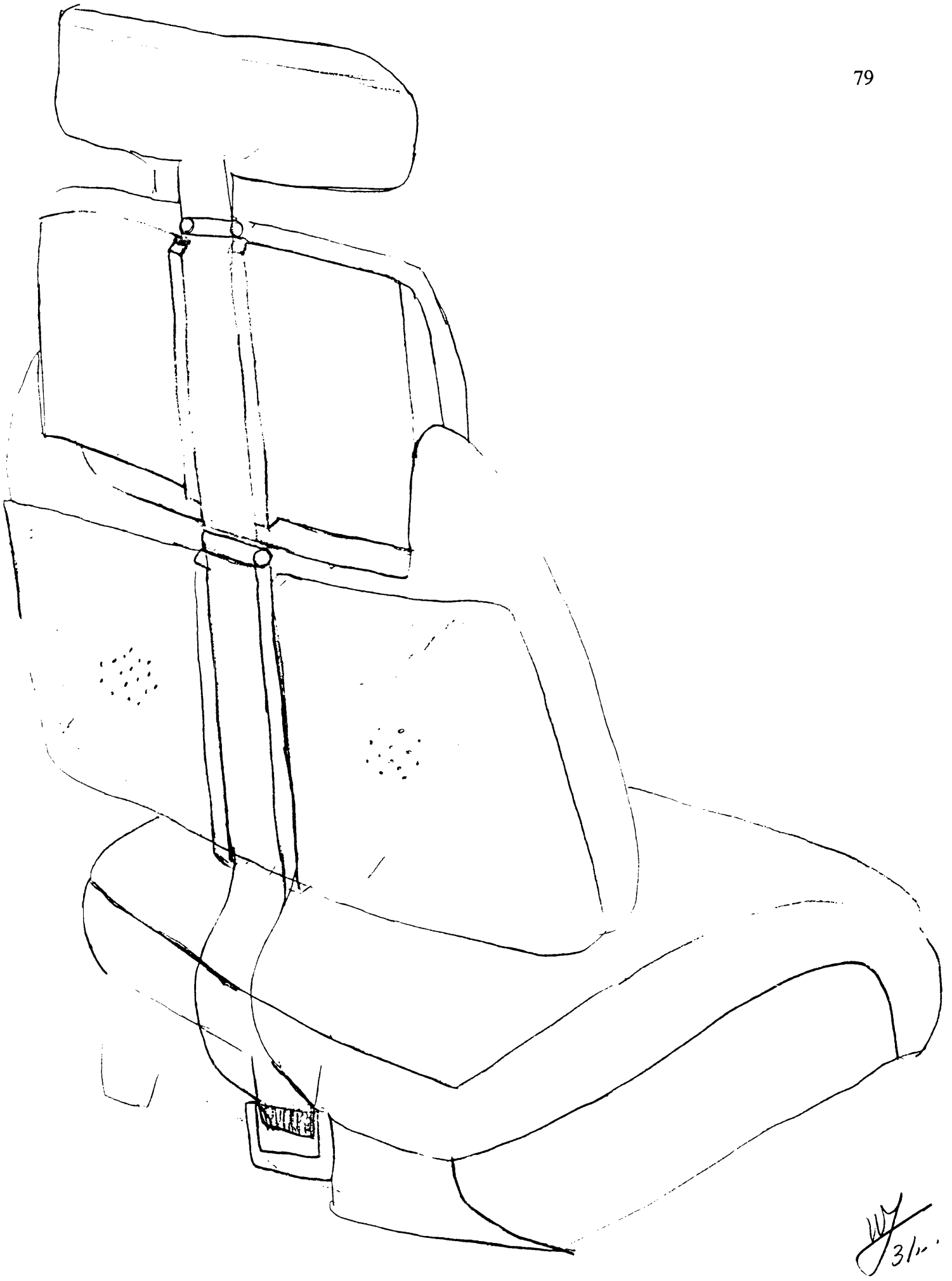
(Three sizes S, M, L)



Controls: Two switches; 1) Vertical location of Lumbar
2) Conforming Lumbar Pad: (Air In/Out)
3) Temperature Setting (70° F.)

Fan

1) Can be used to ventilate occupant
2) Help suck out air from foam pillow.



FLUID FILLED BLADDER

LUMBAR SUPPORT SYSTEM CONCEPT

Multi-Segment, Fluid-Filled,
Self-Adjusting Bladder System

Concept Description

The basic concept for this lumbar-support system is a multi-segment bladder which can be filled with fluid. A single pump can be used to inflate/deflate the bladder from a closed fluid reservoir. The bladder is divided into individual segments with flow passages between them. The flow passages allow fluid flow between the segments such that the average amount of inflation within the bladder is determined by the pump. However, the amount of inflation of individual segments will be a function of the pressure on that segment; e.g. external pressure on some of the segments will force fluid out of them into segments with less external pressure.

As a result, the bladder system will tend to adopt the contour of the back of the individual that is sitting against it. In addition, by adjusting the size of the flow passages, it will be possible to design this system with a contouring time-constant so that as the individual shifts positions, the bladder system will not track instantaeously, but rather will slowly vary to the new contour. Thus, if an the seat occupant is making a rapid adjustment in position (perhaps reaching over to adjust the radio), the bladder system will maintain his/her contour and will not have to re-adjust as he/she sits back in her seat. Alternatively, if the individual re-adjusts position on a permanent basis, the seat contour will slowly adjust (with perhaps a multi-second time constant) to the new position.

An important feature of this concept is that it gives a wide range of flexibility with only a single control (inflate/deflate). In addition, by not instantaneously responding to position shifts, it may give an added sense of comfort due to the variations in support which will accompany small, quick adjustments of body position.

Figure 1 shows a typical implementation of this design. Note that this figure shows an implementation with three separate bladders; a central one for lumbar support and two additional bladders for side support.

Design Issues and Variations

There are a number of variables and variations that must be considered in the design. These include:

- Size of the individual bladder segments can be varied. This will give both courser/finer contouring and also variations in the extent to which the bladder thickness can be varied as it is inflated.
- The thickness and elasticity of the bladder material can be varied.

- The viscocity of the fluid, in combination with the size of the flow passages, will determine the response time of the system.
- More than one multi-segment bladder system can be included in the seat, to give additional flexibility of control. For example, side-support systems could be included along with a lumber support. In addition, seperate systems could be used for the upper- and lower-lumbar regions.
- A small heating element could be built into the bladder to heat the fluid for additional comfort control.

S.D. Umans
March 11, 1992

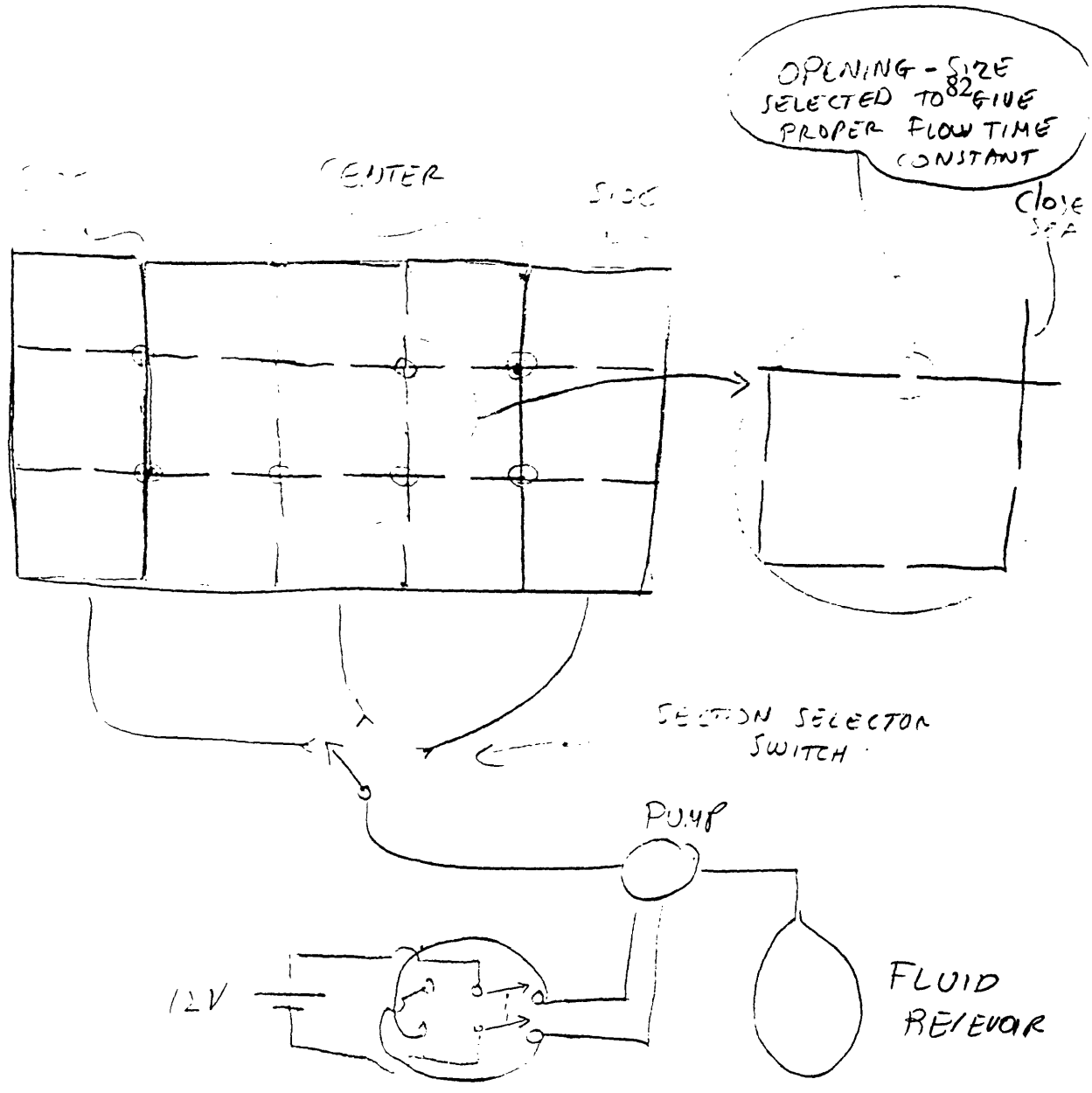


Fig. 1

TYPICAL [illegible] OF MULTI-SEGMENT, FLUID-FILLED, SELF-ADJUSTING BLADDER SYSTEM

TDU 3/11/92

MODIFIED SCHUKRA B

LUMBAR SUPPORT SYSTEM CONCEPT

Presented by: Uwe Mueller
Date: 03/31/92

Objectives

The objective of this concept is to develop a lumbar support system which will provide the following main functions:

- adjustability of vertical curvature
- adjustability of vertical location
- adjustability of horizontal curvature of side support
- quick response to adjustments
- fulfillment of safety issues

Concept Description

Vertical curvature mechanism

The idea is to use excentrically rotating cylinders to get a translational motion. By using a stiff metal grid and gearmotor driven, excentrically suspended, cylindrical drums, the grid can be moved in and out. Having several of those tubes, eventually 3, distributed over the area, will allow the adjustment of the grid curvature over a very wide range. Not only convex but also concave curvatures are possible by having the bands of the grid sliding in slots of the drums, as shown in Figure ( ).

Horizontal curvature mechanism

To provide adjustability of the horizontal curvature also, a bladder with 3-4 chambers will be used at each side in between the metal grid and a support structure, to "bent" the grid sideways and create the desired curvature.

Comments to the concept

This first concept evaluation is based on the list of product requirements determined at the last meeting.

Compatibility with existing seats:
It should be possible to integrate this concept into existing seat-designs since there are no special space requirements.

Quick implementation:
Some parts of the Schukra system could be used to implement it. Three gear-motors are required. The only special parts are the bladders, but I think we could use some of the existing types. The rest can be found in a hardware store.

Overall cost:
Cost is comparable to other existing designs.

Manufacturability:
No special techniques required (can be done at M.I.T.)
The number of parts roughly counted are about 15. To be conservative, I would gues about 30 parts will be required.
The complexity of each part is low compared to existing designs).

Design reliability:
Must be tested but there should not be major problems.

Lateral support:
Is provided through the horizontal curvature. Notice, that a small lateral support around the lumbar region is sufficient (more freedom).

Non confining support:

The horizontal curvature leaves more freedom than side cushions, as seen in one of the GM seats.

Compatibility with proper pelvic orientation:
Given!

Supports overall body weight:
Better than Schukra since it can be better adjusted.

Firmness:
Can be adjusted with different density foam padding.

Capability to reconfigure spinal column:
Very wide range of curvature can be provided and can be chosen in the design by different diameters of drums. Therefore it should be able to reconfigure the spinal column better than Schukra.

Adjustable in the vertical location:
Yes. It will be a compact unit which is easy to move up and down.

Adjustable width:
The width is not adjustable in the sense of side cushions. But the adjustability of the horizontal shape will provide this function as far as it is necessary for the lumbar region.

Conforms to body shape:
The mechanism itself will be stiffer in the vertical curvature than in the horizontal curvature. A multiple density foam padding on top of the grid will provide the desired body fit.

Compliant shape:
Is not given! A compliant shape means a compliant support. In the case of a quick decelleration, as in an impact, the defection of a compliant support will cause high accelerations of the body and can result in injuries.

Controls:
The actual lumbar support shape will be controlled through 3 signals, which may be a lot but can't be reduced for any system unless an intelligent controls system is integrated.

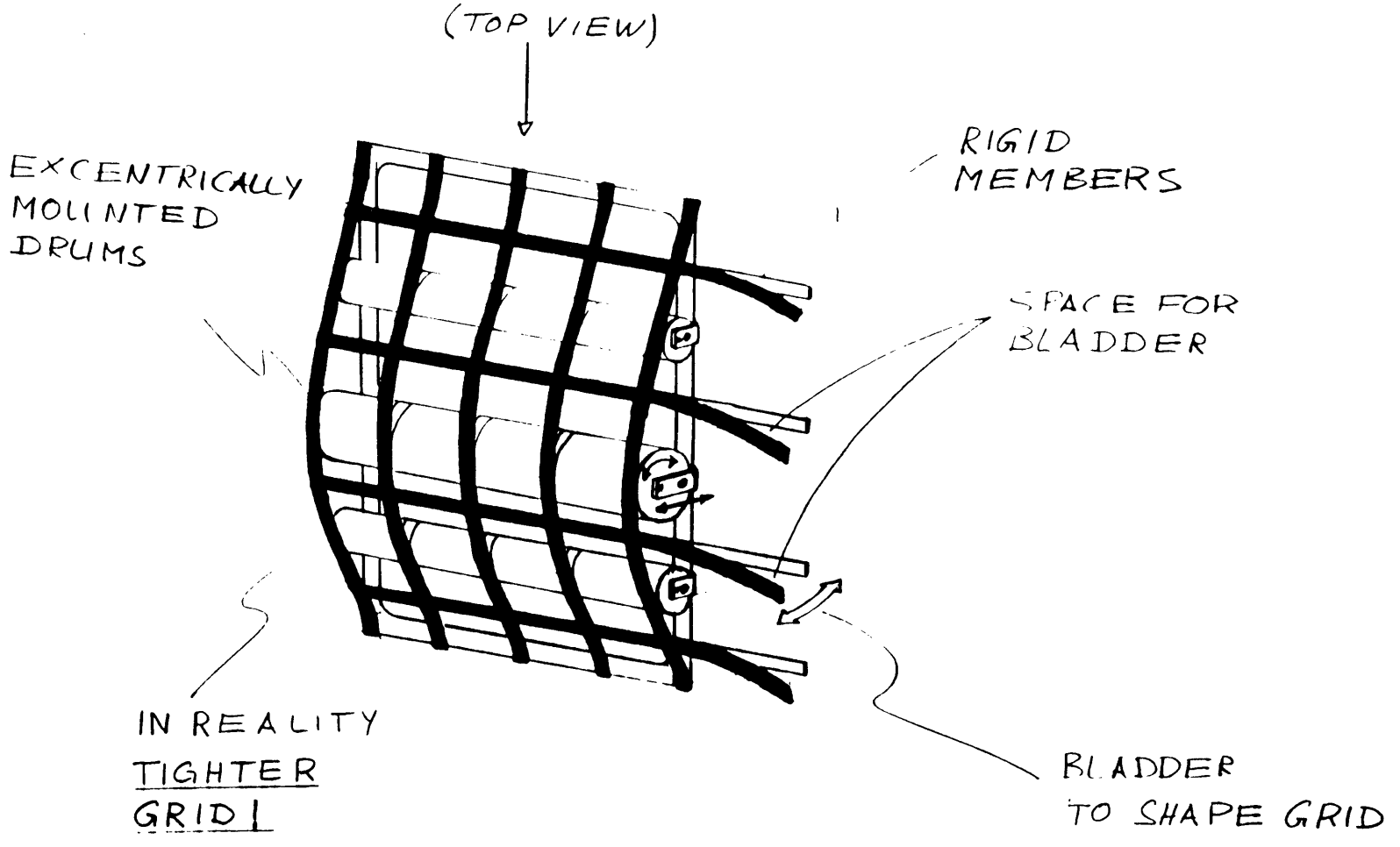
The bladders for the horizontal shape will be controlled with one signal simultaneously. The response of the vertical adjustments will be excellent, since gearmotors will directly drive the mechanism. The response of the bladders will be a bit more sluggish but should be sufficient for the kind of adjustments.

Additional Features

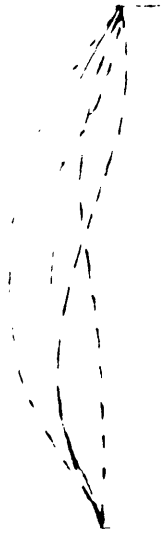
Ventilation and temperature conditioning:
A net of small channels in the surface of the seat material ventilated with preheated air will provide good ventilation and quick heating of the seat.

Time varying configuration:
It would be possible to let the drums automatically rotate a few degrees clockwise and counterclockwise in specified timeperiods around their position setting.

Massage:
A massage feature could possibly provided by slowly rotating
tubes. They would be concentrically located to each drum. These tubes would have flat bulges on their surface to massage the back.

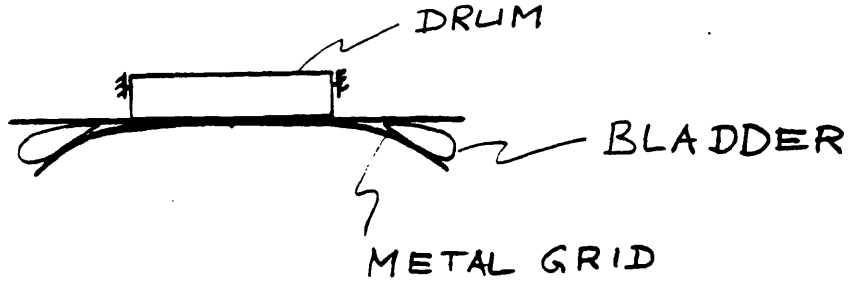

(TOP VIEW)
EXCENTRICALLY MOUNTED DRUMS
RIGID MEMBERS
SPACE FOR BLADDER
IN REALITY TIGHTER GRID
BLADDER TO SHAPE GRID

SIDE VIEW



VARIETY OF POSSIBLE
CURVATURES

TOP VIEW
(CROSS SECTION)



Bladder Matrix#

+/−

Technology

1. Bladder/pumps
2. Vibration
3. Conforming material
4. Simple control

Proven technology + parts

+

- Manufacturability
- Light wt
- Support
- Flexibility
- Can modify existing seat
- Minimal maintenance
- Safe

same sized existing suppliers low cost

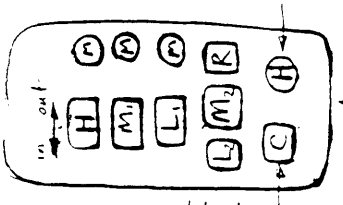
−

User difficul
Noise from pump

in out

Massage Controls

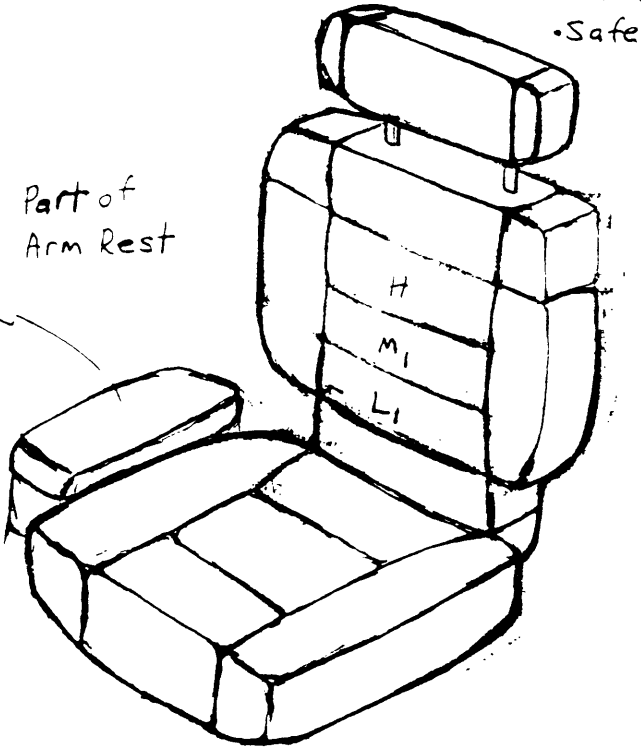
Heat Controls



Vertical Lordosis

Horizontal support

Coxic Support (Optional)



Part of Arm Rest

Support Provided

1. Lordosis
2. Coxic
3. Side
4. Circulation Therm Mass
5. Auditory.
6.

Wing Support (Option

Stereo (Optiona

Surface Materials

A. Detlatable Cushion
B Gel/fluid
C. Foam
D. Wood bead or equivalent
E Memory Foam